GYPSUM: ITS OCCURRENCE, ORIGIN, TECHNOLOGY AND USES

WITH SPECIAL CHAPTERS DEVOTED TO

GYPSUM IN IOWA

BY

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TABLE OF CONTENTS

PAGE

PREFACE

This volume is the outgrowth of an interest in gypsum which has extended over twenty-five years. While the writer was teaching science in the Fort Dodge high school from 1894 to 1897 the gypsum beds furnished a most interesting field for personal study and for class excursions. Later, while he was acting as Assistant State Geologist, the preparation of the report on Webster county was assigned to him, and opportunity was given for further study of the Fort Dodge beds. The Webster county gypsum furnished the theme for a doctor's thesis in 1902. During the past fifteen years an active interest in the industrial applications of gypsum has not lessened interest in the theoretical problems connected with this mineral, while it has led to a study of the literature dealing with its technology and chemistry. The report of the Iowa Survey on Webster county appeared in 1902. Prior to that date Grimsley's reports on the gypsum of Kansas and Michigan had appeared and were of great value to the gypsum industry. D. H. Newland's report on gypsum in New York appeared in 1910 and was followed by Snider's report on Oklahoma gypsum in 1913. R. W. Stone in Bulletin 697 of the United States Geological Survey described American gypsum quite fully and devoted a few pages to technology. A briefer paper along similar lines, by the same author, appeared somewhat earlier as Bulletin 155 of the Bureau of Mines.

Cole's report on gypsum in Canada, and Winterbottom's report for Australia have appeared in recent years and have added materially to the literature on this subject.

In view of the rapid growth of the gypsum industry and particularly on account of the present importance of the industry in Iowa and its great promise for the future, it has seemed proper to prepare a volume which should present all the available information in regard to Iowa gypsum and to supplement this geological study with a statement as complete as possible of manufacturing processes and of uses. The hope may be expressed that the volume will be of service to the industry in general and particularly to the gypsum industry in Iowa.

I wish to acknowledge the assistance received from the works of Pedrotti, V. Waldegg, Grimsley, Newland, Snider, Stone, Cole, Winterbottom, and from the recent writings of Mr. Marani and Dr. Crocker. In connection with the chapter on the origin of gypsum Professor T. C. Chamberlin and Professor Julius Steiglitz have made valuable suggestions. The Bureau of Standards and particularly Mr. Emley and Mr. Hull have made investigations and published papers on gypsum which are of great value. Members of Committee C-11 of the American Society for Testing Materials have contributed valuable information which is acknowledged at various places.

The topographic map has been prepared by the United States Geological Survey co-operating with the Iowa Geological Survey. The value of such a map for industrial and mining purposes is apparent. At the same time it furnishes an essential base on which to present the geology of the region.

Thanks are due the gypsum companies in Iowa, makers of gypsum machinery, and the Gypsum Industries Association for illustrative material.

Dr. James H. Lees has rendered valuable assistance in connection with all of the recent field work in Webster county and his aid was particularly valuable in connection with the preparation of sections of the Fort Dodge beds.

The engineering department of the State University conducted important physical tests and the chemical department made analyses of numerous samples from Fort Dodge and Centerville.

The assistance of Doctor Lees and Miss Newman in preparing the monograph for the press is gratefully acknowledged.

Respectfully,

FRANK A. WILDER.

GYPSUM

CHAPTER I

PHYSICAL AND CHEMICAL PROPERTIES OF GYPSUM

According to its texture, or crystalline structure, gypsum is known as massive gypsum, as selenite and as satin spar. These three varieties are alike in their specific gravity, in hardness and in solubility.

Hardness

Gypsum is one of the softest minerals, its hardness being placed at 1.5 to 2 in the Mohs scale, and it may be easily scratched with the finger nail. It lacks the greasy feel that characterizes other soft minerals like talc, soapstone, and graphite.

Weight

The specific gravity of gypsum, (that is its weight as compared with an equal volume of pure water) is 2.3 to 2.4. The specific gravity of a number of familiar substances is given in the following table, for purposes of comparison.

Limestone	2.46 to 2.84
Quicklime	2.30 to 3.18
Lime mortar	1.64 to 1.86
Gypsum	2.30 to 2.40
Anhydrite	2.90 to 2.98
Calcined Gypsum	1.81
Portland Cement	2.72 to 3.05

Weights of gypsum[1]

		Weight in lb. per cu. ft.[1]
(1)	Natural gypsum rock, free from surface water, not calcined, in block form	140 to 145
(2)	Crushed gypsum rock not calcined, all to pass through 1 inch ring	90 to 100
(3)	Gypsum rock ground so that 90 per cent of product will pass 100 mesh screen, dried of all free moisture, not calcined, commonly known as land plaster	75 to 80
(4)	Gypsum rock ground so that 90 per cent will pass 100 mesh screen, calcined, commonly known as stucco or plaster of Paris—	
	Loose	56 to 65
	Well shaken down or in bins	65 to 75
(5)	Plaster of Paris or stucco mixed with water into a stiff mass, such as mortar, set and dried out	77

Solubility

Gypsum is somewhat soluble in water, the solubility varying with the temperature, as shown in the following table of Marignac which has been verified by Grimsley.[2]

[1]These figures were submitted in 1918, by V. C. Marani for use in Kidder's Architects' and Builders' Pocket-Book.

[2]Annales de Chimie Paris, 5th Ed., Vol. I, pp. 274-281. Quoted by Chatard, 7th Ann. Rept. U. S. Geol. Survey, and by Grimsley in the Univ. Geol. Survey of Kansas, Vol. V. p. 86.

Temperature	One Part Gypsum Dissolves in	One Part Anhydrous Sulphate Lime Dissolves in
At 32 °F— 0°C	415 parts of water	525 parts of water
At 64.5°F— 18°C	386 parts of water	488 parts of water
At 75.2°F— 24°C	378 parts of water	479 parts of water
At 89.6°F— 32°C	371 parts of water	470 parts of water
At 100.4°F— 38°C	368 parts of water	466 parts of water
At 105.8°F— 41°C	370 parts of water	468 parts of water
At 127.4°F— 53°C	375 parts of water	474 parts of water
At 161.6°F— 72°C	391 parts of water	495 parts of water
At 186.8°F— 86°C	417 parts of water	528 parts of water
At 212 °F—100°C	452 parts of water	572 parts of water

H. S. Gale[3] sums up certain investigations of Van't Hoff and Meyerhoff, stating that they "have shown that the solubility of gypsum gradually increases with rise of temperature from about 0.18 per cent at 0°C (32°F) to a maximum of about 0.21 per cent at about 40°C (104°F). With further increase in temperature the solubility steadily decreases until at 100°C (212°F) it is again 0.18 per cent or about the same as it was in ice water. The solubility may be increased more than three times by the addition of sodium chloride and more than four times by the addition of magnesium chloride.

"In summary the authors cited state that there are but two forms of calcium sulphate which are stable in the presence of any solution—gypsum and natural anhydrite—and the stability of one or the other form depends on the temperature and nature of the solution with which it is in contact. In pure solution gypsum is stable only up to 66°C when it begins to be transformed into anhydrite, but as the change takes place slowly the solubility may be determined beyond the point of its stability."

Compressive strength

The compressive strength of gypsum is a matter of great practical importance, inasmuch as the load that may be assigned to gypsum pillars in the mine is directly dependent on this property.

A test of the compressive strength of the Fort Dodge gypsum was made by the Watertown Arsenal in 1894, and the specimen showed strength sufficient to sustain a pressure of 2900 pounds per square inch.[4]

More elaborate tests have been made on three six-inch cubes

[3]U. S. Geol. Survey, Bulletin 580, p. 302.

[4]S. W. Stratton, Director Bureau of Standards, in personal letter to the writer, dated April 29, 1914.

of Virginia gypsum and the results are closely in line with the single recorded test on the Fort Dodge mineral. The report of the Bureau of Standards follows:

Gentlemen:

Enclosed is a report of compression tests on three of the cubes of gypsum rock sent to this Bureau. Cube No. 2721 was previously soaked in water for two days and crushed by bringing the load on the bed faces; No. 2722 was crushed dry by loading parallel to the bed faces, and No. 2723 was crushed dry on the bed faces.

Respectfully,
S. W. STRATTON,
Director.

COMPRESSION TESTS ON THREE CUBES OF GYPSUM

Submitted by

SOUTHERN GYPSUM COMPANY, NORTH HOLSTON, VIRGINIA

LAB. NO.	DIMENSIONS FACES IN.	HEIGHT IN.	AREA SQ. IN.	ULTIMATE LOAD LBS.	COMPRESSIVE STRENGTH LBS. PER SQ. IN.	REMARKS
2721	5.97x5.98	6.00	35.70	105001	2944	Wet-loaded on bed
2722	6.00x5.98	5.98	35.88	93900	2617	Dry-loaded on edge
2723	5.90x5.90	5.98	34.81	112220	3224	Dry-loaded on bed

The amount of water absorbed by a specimen of Virginia gypsum, as determined by the Bureau of Standards at Washington, is as follows:

Absorption

TEST NO. 16143 LAB. NO. 2724

Percentage of water absorption by weight........ 0.20

The method of testing as described in a letter from the Bureau of Standards was as follows:

"The gypsum was cut into cubes approximately three inches on the side, which were dried in the laboratory for several weeks. The cubes were then weighed, and this weight recorded as the dry weight. It should be noted that it was not possible to dry these cubes by heating on account of the readiness with which the composition of this material is changed. After obtaining the weight of the cubes which were dried in the laboratory, they were placed in a basin containing alcohol, and allowed to stand 48 hours. They were next weighed, and the increase in weight obtained was reduced to the equivalent weight of water. This equivalent weight was divided by the dry weight of the cubes, and multiplied by 100, which gave the percentage of water absorption by weight.

"The reason for using alcohol instead of water was because it was found that the water dissolved a considerable amount of the gypsum when the test was made in the usual way. However, it may be pointed out that in the method used, it was assumed that alcohol would be absorbed to the same degree as water, an assumption which may not be warranted. We are inclined to believe now that a better determination could be made with special apparatus using water, and making a correction for solubility."

Varieties

Several varieties of gypsum are recognized, depending on the presence or absence of crystalline structure, crystalline form and color.

Selenite

Selenite is generally colorless, and is to some degree transparent, in many cases completely so. It possesses remarkably perfect cleavage and splits into thin plates like mica, from which it can be distinguished by its lack of flexibility and its crumbling on exposure to heat.

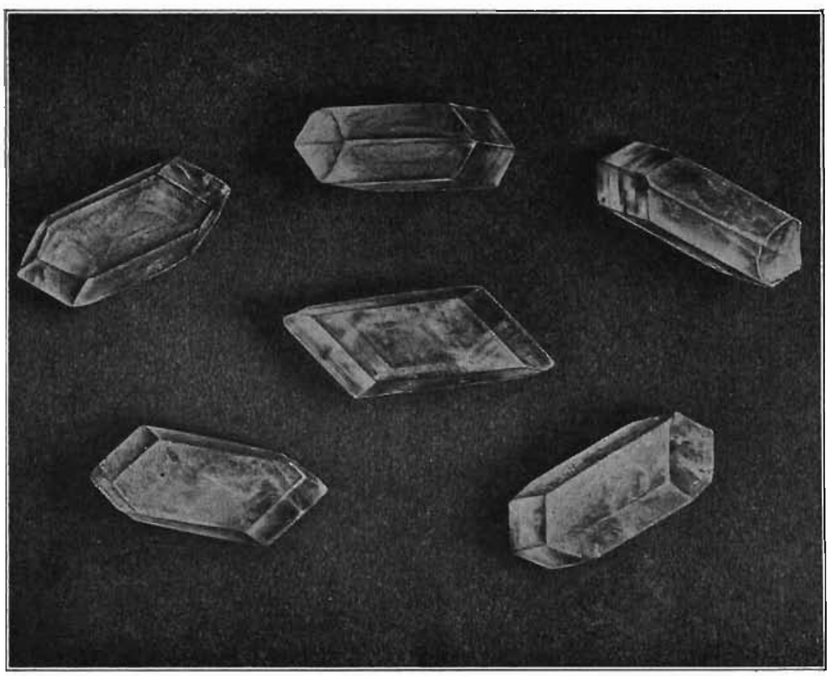


FIG. 1.—Gypsum crystals as developed when growth in all directions is unimpeded. Such crystals are found in the Coal Measures shales about Fort Dodge. More slender forms, often twinned, are found in the Mississippian marls north of Fort Dodge. Courtesy U. S. Geol. Survey.

Selenite often occurs in distinct crystals, which belong to the monoclinic system. The relative length of the axis is represented by the formula 0.6891: 1 : 0.4156 and the angle of the inclined axis to the vertical is 81°5′. Twin crystals are common, the twinning being on the orthopinacoidal face. Beautiful selenite crystals, both individuals and twins, may be found in the Coal Measures clays of Iowa, and in the Cretaceous clays of the northwestern part of the state. The typical forms are shown in figures 1 and 2.

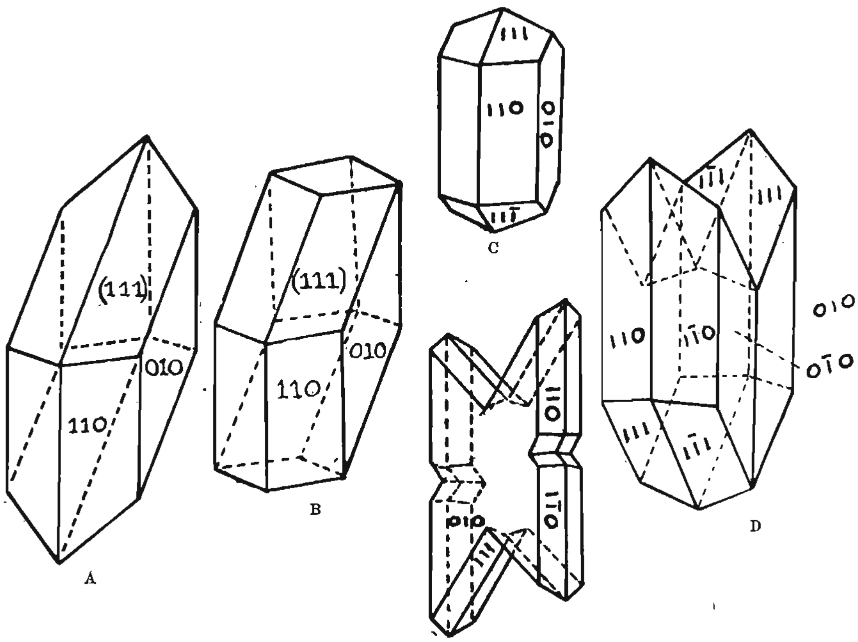


FIG. 2,A, B, C, D, E.—Diagrams of gypsum crystals. D shows the common method of twinning. Courtesy Illinois State Museum.

Selenitic gypsum, which consists of masses of crystals so intergrown as to lose their individual outline, forms solid beds in Oklahoma[5] and Texas.[6] Veins of selenite from eight to twenty feet thick and extending for half a mile along the strike of the gypsum beds which they cut are reported as occurring in Nova Scotia.[7] Selenite crystals, usually in rosettes or clusters

[5]Gould, Oklahoma Geol. Survey, Bulletin No. 11, p. 6.
[6]Dumble, E. T., Selenite at Loma Blanca. Mineral Industry, Vol. XXIV, p. 378.
[7]Cole, L. H., Gypsum in Canada. Canada Dept. Mines, Mines Branch, No. 245, p. 190, 1913.

are often found scattered through massive gypsum and anhydrite. An example of this intergrowth is shown in figure 3.

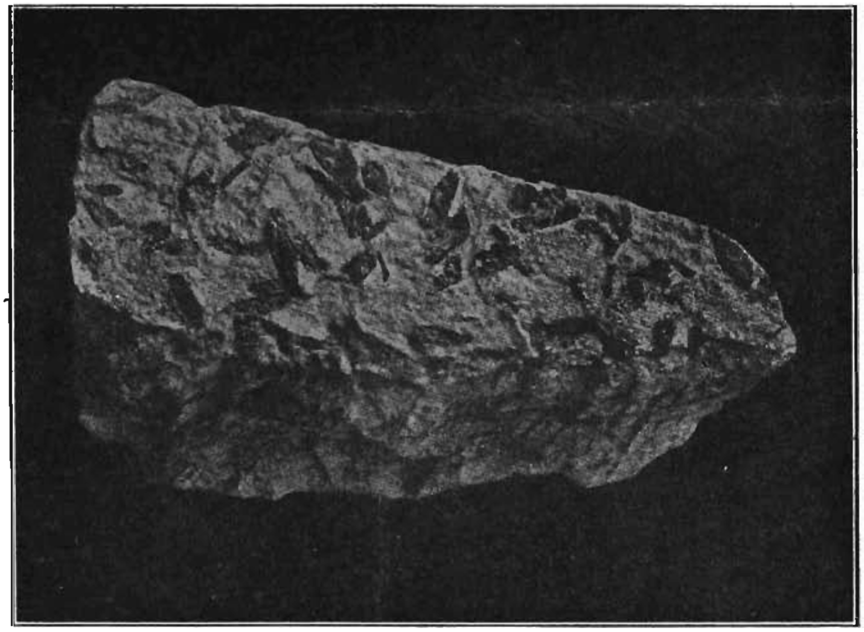


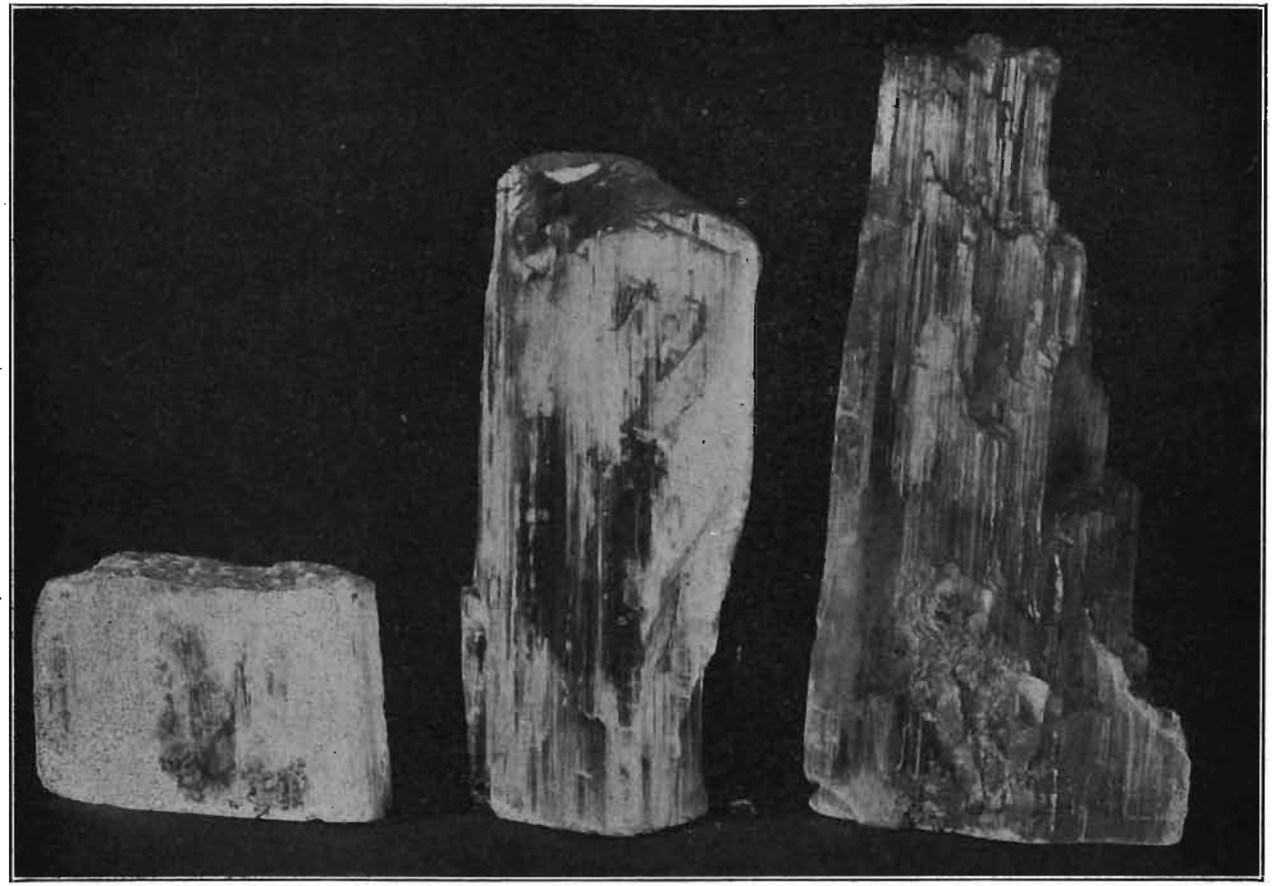
FIG. 3.—Selenite crystals imbedded in gypsum. In a similar manner gypsum crystals are often surrounded by fine grained anhydrite. Canadian Mining Journal.

Such occurrences may be noted in the anhydrite of Centerville, Iowa. Some beautiful crystals from the Centerville mine are illustrated in Plate II.

Satin spar

Satin spar is gypsum that has been deposited from solution along cracks and crevices and in cavities, and has taken the form of long slender crystals. Deposition took place along both edges of the crevice and the pressure created by the growing crystals has been sufficient in many cases to develop a crack several inches across, which the satin spar mass completely fills. Veins of satin spar from twelve to eighteen inches wide are reported as occurring in marls in Nova Scotia.[8] Satin spar is generally white in color and has a silky luster. The beautiful rosettes of gypsum lining the walls in certain parts of Mammoth cave are like satin spar in their origin and nature. Satin spar is illustrated in figures 4 and 5.

[8]Cole, L. H., Op. cit., p. 210.



Selenite crystals from Centerville, presented to Iowa Geological Survey by Scandinavian Coal Co. Crystalline forms are only partly developed. Cleavage specimens of great beauty, ten inches or more in length were found in the cave in the gypsum mine at Centerville.

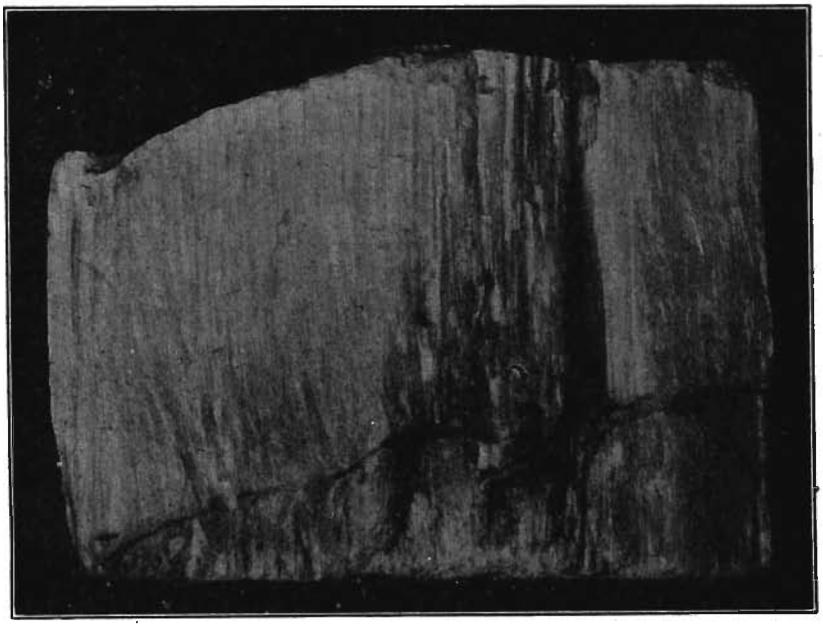


FIG. 4.—Satin spar, or fibrous gypsum. In many gypsum producing localities satin spar is found abundantly as veinlets and in veins up to two or three inches in thickness, in the associated clays. The figure shows the parting that is commonly present, indicating crystalline growth in opposite directions, from an originally small crack carrying mineral in solution, outward, or from the sides of an open fissure, inward. Courtesy U. S. Geological Survey.

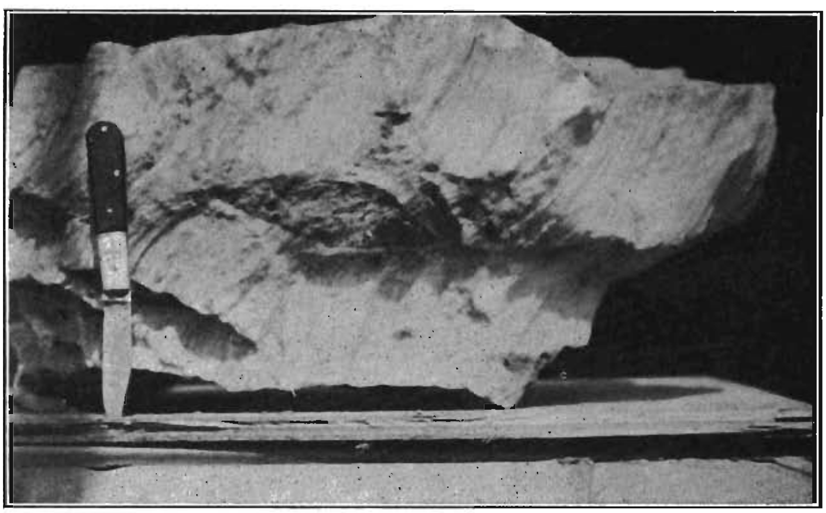


FIG. 5.—Satin spar with clay inclusion. Explained by supposing a fractured zone in the clay traversed by mineralized waters. The growing crystals enlarged the cracks and surrounded portions of clay included between the cracks. Photo by Wilder.

Rock gypsum

Massive or rock gypsum occurs in large bodies, in some localities, over extensive areas and in beds that attain a thickness of a hundred feet. It furnishes most of the gypsum that is used for industrial purposes. It presents a considerable variety in color, texture and structure. Pure white gypsum is common, though grayish white is more abundant, while browns and grays and more rarely pink may be noted. From coarsely crystalline it ranges downward to fine granular in texture. In structure it may show distinct bedding planes along which it breaks easily, or it may occur as a compact body lacking in bedding and jointings. The distinct bedding of the Fort Dodge gypsum is one of its striking characteristics and aids greatly in winning the mineral in the mine and quarry.

Alabaster

Alabaster is massive gypsum crystalline in texture and white in color, which is used to some extent for statuary and vases and for ornamental slabs where hardness is not essential.

Flour gypsum and seed gypsum are descriptive terms given by Winterbottom[9] to extensive deposits in South Australia. Flour gypsum is fine granular mineral, purer than the American variety known as gypsite, which is described in a later paragraph. Seed gypsum is coarsely granular, and apparently is like the gypsum sands about Alamogordo, New Mexico.

Gypsite

Gypsite consists of small detached crystals of gypsum scattered through fine clay or loam so abundantly that they form eighty to ninety per cent of the entire mass. It occurs as extensive surface deposits in several of the western states, and is of considerable economic importance.

Chemical composition

Considered chemically, gypsum has for its formula $CaSO_4 2H_2O$. When it is pure the various constituents give the following percentages by weight:

Gypsum ($CaSO_4 2H_2O$)	Lime sulphate ($CaSO_4$)	Lime (CaO)	32.6
		Sulphur trioxide (SO_3)	46.5
	Water H_2O		20.9
			100.0

[9] South Australia, Department of Chemistry, Bulletin No. 7, Gypsum and Plaster of Paris

Some typical analyses of hand samples, selected by F. W. Clarke, Chief Chemist, U. S. Geological Survey, are given below.[10]

Type analyses

A. From Hillsboro, New Brunswick. Analysis by George Steiger.
B. From the Western Plaster Works, Alabaster, Michigan. Analysis by George Steiger.
C. From east of Cascade, Black Hills, South Dakota. Analysis by Steiger.
D. From Rico-Aspen mine, Rico district, Colorado. Analysis by W. F. Hillebrand.
E, F. From Nephi, Utah. Analysis by E. T. Allen. Some anhydrite must be present.

	A.	B.	C.	D.	E.	F.
SO_3	46.18	46.18	45.45	45.07	48.14	39.53
CO_2	...	...	.85	1.54	.65	7.73
Cl	trace	.03	...	...	trace	.04
SiO_2	...	...	.10	.51	...	...
TiO_2	...	...	...	trace	...	...
Al_2O_3	.10		.12	.03	...	
Fe_2O_3		.08	...	.09	...	.14
CaO	32.37	32.33	32.44	32.49	35.29	38.46
SrO	...	...	...	.10	...	...
MgO	trace	.05	.33	.92	trace	.24
Na_2O		.14	...	trace	...	.07
K_2O	.10		...	...	...	.19
H_2O	20.94	20.96	20.80	19.67	15.88	12.69
Insoluble	.10	.05	...	...	...	.45
Organic matter	...	...	...	present	...	...
	99.79	99.82	100.09	100.42	99.96	99.54

Analyses of gypsum from a number of other localities appear in the following table, and with them analyses of two samples of gypsite.[11]

10U. S. Geol. Survey, Bulletin 419, p. 307.
11U. S. Geol. Survey, Mineral Resources of the United States 1906, p. 1069, Burchard, Ernest F., Gypsum and Gypsum Products.

ANALYSES OF GYPSUM AND GYPSITE

	Silica (SiO_2)	Alumina (Al_2O_3 and iron oxide (Fe_2O_3)	Lime carbonate ($CaCO_3$)	Magnesium carbonate ($MgCO_3$)	Lime sulphate ($CaSO_4$)	Water (H_2O)
1	0.40	0.19	0.25	0.35	78.10	20.36
2	.05	.08	....	.11	78.51	20.96
3	.68	.16	Not det.	Not det.	78.08	20.14
4	.10	.70	....	....	79.26	19.40
5	.10	.10	....	....	78.55	20.94
6	.11	....	1.07	....	78.42	20.43
7	3.62	.45	4.09	.34	71.94	19.87
8	9.73	.78	4.32	Trace	68.29	16.88

1 Gypsum from Blue Rapids, Kansas
2 Gypsum from Alabaster, Michigan
3 Gypsum from near Sandusky, Ohio
4 Gypsum from Saltville, Virginia
5 Gypsum from Hillsboro, New Brunswick
6 Gypsum from Baddeck Bay, Nova Scotia
7 Gypsite from Gypsum City, Kansas
8 Gypsite from Salina, Kansas

A number of analyses of Oklahoma gypsum appear below:[12]

	A	B	C
Calcium sulphate	74.45	77.38	63.82
Calcium carbonate	4.25	---- ----	4.86
Magnesium carbonate	.84	---- ----	.14
Magnesium sulphate	---- ----	.83	---- ----
Water	18.61	20.78	16.43
Oxides of iron and aluminum	.61	.67	.69
Silica and insoluble residue	1.02	.41	13.95

A. From vicinity of Cement, Oklahoma.
B. From ledge four miles west of Weatherford.
C. Gypsite near Cement, Oklahoma.

12Oklahoma Geol. Survey, Bulletin No. 11, p. 179, 185, 187.

The average composition of the 'run of mine'' New York gypsum as given by Merrill,[13] is as follows:

	1	2	3	4	5	6
SiO_2	.51	1.03	.40	2.93	8.31	4.00
Al_2O_3	1.19	.41	2.97	1.92	4.53	1.74
Fe_2O_3	.79	1.27	.77	1.10	1.34	1.11
CaO	30.62	30.74	30.76	26.27	21.50	29.36
MgO	1.20	2.01	1.53	8.29	7.20	2.81
SO_3	43.59	42.39	43.78	33.83	30.47	35.79
CO_2	1.02	2.20	2.80	11.02	9.50	6.38
H_2O	20.52	18.19	17.53	14.87	14.53	17.93
	99.44	98.24	100.54	100.23	97.38	99.12
Gypsum calculated	93.74	91.27	94.26	72.84	65.49	77.06

1. Akron, Erie county.
2. Oakfield, Genesee county.
3. Oakfield, Genesee county.
4. Garbutt, Monroe county.
5. Lyndon, Onondaga county.
6. Lyndon, Onondaga county.

Two analyses from Colorado and from Wyoming, quoted by Grimsley, are interesting.[14]

	Aspen District, Colorado	Red Buttes, Wyoming
Silica and insoluble material	1.46	4.50
Iron and alumina oxides	---- ----	1.27
Lime sulphate	69.26	64.22
Lime carbonate	5.96	15.74
Water (calculated)	21.50	14.00
Magnesium carbonate	1.32	---- ----

ANALYSES OF MICHIGAN GYPSUM[15]

	A	B	C	D
Silica and insoluble material	1.28	1.18	.55	.19
Iron and aluminum oxides	1.82	1.87	trace	---- ----
Lime sulphate	79.98	76.02	77.76	77.93
Lime carbonate	1.95	2.57	1.86	1.25
Water	19.00	19.00	20.28	20.32
Magnesium carbonate	trace	---- ----	---- ----	---- ----

A. Alabastine quarry, Grand Rapids; B. English Shaft, Grand Rapids; C. Alabaster, Michigan; D. St. Ignace.

13Bulletin New York State Museum, Vol. III, p. 81, 1893.
14Geol. Survey of Michigan, Vol. 9, p. 146.
15Geol. Survey of Michigan, Vol. 9, pp. 153-154.

ANALYSES OF GYPSUM FROM NEAR CASCADE SPRINGS, SO. DAK.[16]

Lime (CaO)	32.44
Magnesia	.33
Alumina	.12
Silica	.10
Sulphuric anhydrite (SO_3)	45.45
Carbon dioxide (CO_2)	.85
Water (H_2O)	20.80
	100.09

ANALYSES OF GYPSUM FROM MONTANA

	1	2	3
CaO	32.5	33.02	33.10
Al_2O_3	.3	---- ----	---- ----
Fe_2O_3	trace	---- ----	---- ----
SiO_2	.2	---- ----	---- ----
SO_3	46.3	45.93	45.94
H_2O	20.8	21.04	20.96

1. Gypsum from Red Buttes, U. S. Geol. Survey Bulletin No. 285, p. 405.
2. Gypsum near Bowler, U. S. Geol. Survey Bulletin No. 285, p. 314.
3. Gypsum near Kibbey, American Geologist, 1905, pp. 104-113.

Iowa

Analyses of the gypsum of Fort Dodge and Centerville, Iowa, are discussed at length in Chapter VII.

Australia

Analyses of flour and seed gypsum from Lake Fowler, Yorke Peninsula, South Australia, are particularly interesting.[17] The physical conditions under which these deposits occur are described in Chapter II.

[16]Steiger, George, U. S. Geol. Survey, Bulletin 223, p. 78; Bulletin 697, p. 248.
[17]Dept. of Chemistry, South Australia, Bulletin No. 7, p. 22.

	Seed Gypsum	Seed Gypsum	Flour Gypsum	Flour Gypsum
	1	2	3	4
Lime, CaO	31.75	33.00	32.30	32.30
Sulphuric Anhydrite, SO_3	44.90	44.45	43.60	44.90
Water, Combined, H_2O	20.20	20.10	19.60	20.10
Water, Moisture, H_2O	0.20	0.20	1.10	nil
Carbon Dioxide, CO_2	0.15	1.50	1.50	1.10
Aluminum and Ferric Oxide	0.20	0.20	trace	0.10
Insoluble	2.00	0.14	1.10	1.15
Organic Matter	0.40	0.40	0.70	0.35
Equivalent gypsum content—				
$CaSO_4 2H_2O$	96.85	95.60	93.70	96.30
Specific gravity	2.3			

The gypsum of the Paris basin contains from ten to twenty per cent of calcium carbonate and according to Dammer and Tietze[18] "also silica in a soluble form so that calcined gypsum from this material sets decidedly harder."

The water of crystallization which appears in all analyses of gypsum is given off either wholly or in part when the mineral is heated, and the products derived from gypsum by heating or calcination have valuable properties which are discussed in later chapters.

ANHYDRITE

Anhydrite is a mineral closely related to gypsum chemically and in point of origin. Gypsum under certain conditions is changed into anhydrite while under other conditions the opposite transformation takes place. Chemically, anhydrite is gypsum without water of crystallization and has for its formula simply $CaSO_4$.

Its hardness is 3 to 3.5 in the Mohs scale, or about that of ordinary limestone. In mining where gypsum and anhydrite occur together, the greater hardness of anhydrite must be considered in selecting equipment. The miners easily recognize the greater weight of anhydrite, which has a specific gravity of 2.9 as compared with 2.3 for gypsum.

Hardness and weight

Anhydrite is generally white, with a bluish or grayish tinge.

18Die Nutzbaren Mineralien, II, p. 67.

In rare instances it is red. Its texture is commonly fine granular, though fibrous masses and orthorhombic crystals with three good cleavages are found. Chemically pure anhydrite contains 58.8 per cent SO_3 and most anhydrite will show 54 to 56 per cent SO_3, the impurities present being usually the same that are found in gypsum.

Color, texture and composition

Anhydrite is found in distinct beds, and in some cases it occurs as lenses in gypsum. Crystals of gypsum are frequently found scattered throughout anhydrite, giving the latter mineral a porphyritic texture.

Structure

CHAPTER II

DESCRIPTION OF IMPORTANT DEPOSITS OF GYPSUM IN THE UNITED STATES AND IN FOREIGN COUNTRIES

Within the United States there are numerous deposits of gypsum of sufficient size to render them commercially important. They occur in New York, Virginia, Ohio, Michigan, Iowa, Missouri, Kansas, Oklahoma, Texas, Montana, South Dakota, Wyoming, Colorado, New Mexico, Arizona, Utah, Oregon, Nevada, California and Alaska. A peculiar deposit in Florida is of scientific interest but has not proved of commercial value. To the north of the United States valuable deposits are found in Nova Scotia, New Brunswick, Ontario, Manitoba and British Columbia.

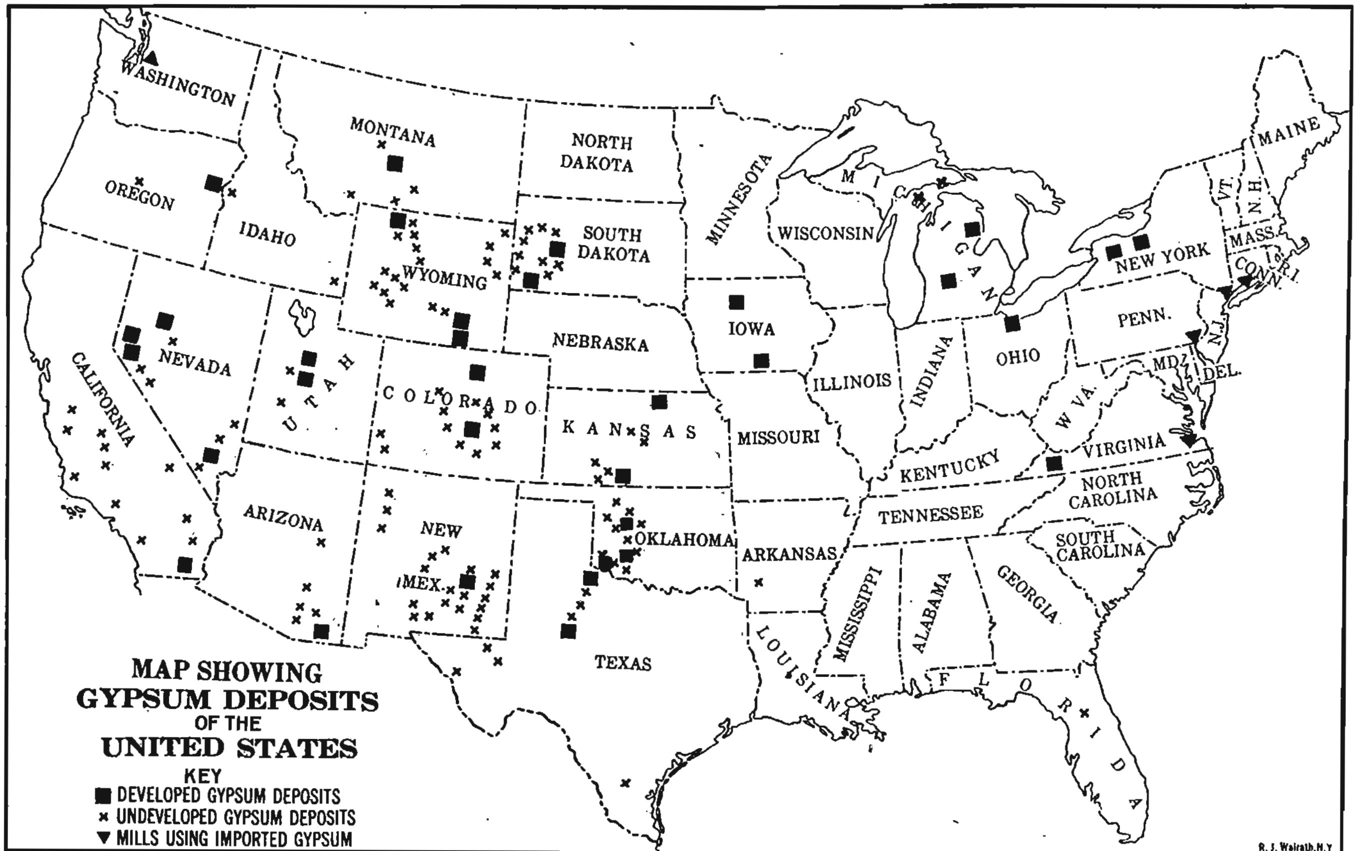
In Europe there are notable deposits in England, France, Germany, Switzerland, Russia and Italy. Asia, Africa and Australia possess gypsum areas which will be briefly referred to in subsequent pages.

The gypsum deposits of the United States are shown on Plate III. Brief descriptions follow, arranged alphabetically with reference to the states and territories in which the deposits occur.

Alaska

E. F. Burchard states[19] that "the only extensive gypsum deposit known in southeastern Alaska is operated by the Pacific Coast Gypsum Co., and is situated in the eastern part of Chicagof Island, about a mile from Iyoukeen Cove. The limits of the deposit have not yet been ascertained. At the surface the deposit is covered with gravel except near the shaft house, and no footwall nor hanging wall has been encountered in the mine workings. Several solution channels filled with gravel more or less cemented have been encountered in mining. The gravel is of the same character as that in the bed of Gypsum Creek. The gravel-filled channels extend below the 160-foot level. One channel has been tunneled for 35 feet without being cut through. Thin dikes of basaltic rock cut the gypsum beds, and a vein of anhydrite ranging in thickness from 6 inches to more than 10 feet has been encountered in the lower work-

19U. S. Geol. Survey, Mineral Resources 1913, Part II, p. 363. Also Gypsum Deposits of the United States, Bulletin 697, p. 47, 1920.



Map showing the location of gypsum deposits and gypsum mills in the United States.

ings. This anhydrite is much harder to drill than the inclosing gypsum, and it is left in the mine. The gypsum is generally of a light bluish-gray color, although some is white, and occurs in massive beds, which dip 30°-60° NE. The main body of gypsum is of a high degree of purity.

The mine shaft is 315 feet deep. The first level is at 75 feet and the second at 160 feet. The general trend of the gypsum deposit is in a direction slightly north of west, and the levels extend for 750 feet east and west and 270 feet north and south, with the shaft near the middle of the exploited area. Altogether the underground workings are reported to measure probably 1 mile. Overhand stoping is the method employed in mining, and considerable broken gypsum rock is stored in the stopes.

The gypsum is hoisted to rock bins of 1,200 tons capacity, from which it is dumped into tramcars and drawn by a steam locomotive to the wharf. Shipments of crude gypsum are made by barges to Tacoma, Wash., where the material is calcined and manufactured into wall plaster of various grades in the company's plaster mill.

Adjoining on the east the claims now being worked for gypsum by the Pacific Coast Gypsum Co. and extending to the shore of Chatham Strait are other claims which have been located on reported deposits of gypsum."

Arizona

Gypsum deposits of considerable extent occur in Arizona, but on account of their remoteness from markets, and the abundance of gypsum in adjoining states, they are not extensively developed. The only mill and mine in the state is located at Douglas, operated by the Arizona Gypsum Plaster Company. A buff colored gypsite is used, which is hauled five miles by tram to Douglas.[20]

According to R. W. Stone there are indications of a ten foot bed in Land county about one mile west of the town of Land, a station on the El Paso and Southwestern Railroad.

In Mohave county W. T. Lee[21] found extensive beds of gypsum and gypsiferous clays in Virgin Valley, while Stone states that thick ledges of excellent gypsum are reported to occur in South Mountain and Quail Canyon fifteen miles south of St. George.

A large amount of gypsum was shipped before 1914 from the

20Stone and others, Gypsum Deposits in the United States: U. S. Geol. Survey, Bull. 697, p 49, 1920.

21U. S. Geol. Survey, Bull. 352, p. 26, 1908.

town of Winslow in Navajo county to California points. On account of increased freight rates shipments have been discontinued. The bed is from four inches to four feet thick and averages eighteen inches in thickness. The mineral was hauled to Winslow on tram cars.

Stone states that in the Empire mountains in Pima county there occur two beds of gypsum, each fifty feet thick and separated by a thin bed of limestone.

W. P. Blake reported[22] that gypsum occurred in the Santa Catalina mountains north of Tucson, and was calcined for local use. Stone,[23] in 1919, could not locate any quarry or mine answering to Blake's description. Eight miles northeast of Tucson pits eight to ten feet deep have been sunk to a bed of gypsum four and one-half feet thick.

Near Feldman in Pinal county a thirty foot bed of good gypsum occurs but the distance from the railroad makes it of doubtful commercial importance.

Arkansas

Gypsum is found in Pike and Howard counties, Arkansas.[24] The thickest exposure is in Plaster Bluff southwest of Murfreesboro in Pike county, sixty-five feet above Little Missouri river. A single bed ranging from ten to fourteen feet in thickness is pure saccharoidal gypsum, with some thin seams of satin spar, and as much as three feet of interbedded clay in its lower part. The thickest layer of gypsum is at the top of the bed and measures four feet. Gypsum not exceeding three feet thick is found as far west as Messers creek in Howard county. In Arkansas the occurrence of gypsum is so restricted that the gypsum has practically no commercial value, although it could be produced in a small way for purely local use.

California

The more important deposits of gypsum in California lie south of San Francisco Bay. Considerable interest is being taken in these deposits and California promises to become an important gypsum producing state. In 1919 the Pacific Coast Gypsum Company was operating a plant at San Francisco, and the United States Gypsum Company one at Amboy.

At Point Sal, Santa Barbara county, and at Palmdale, Lang,

22Gypsum Deposits of Arizona, U. S. Geol. Survey, Bull. 223, pp. 100-101, 1904. Also Bull. 697, pp. 49-56.

23Gypsum Deposits of the United States, U. S. Geol. Survey, Bull. 697, 1920.

24Gypsum Products, their Preparation and Uses: Bureau of Mines, Technical Paper 155.

and Castaic in Los Angeles county gypsum deposits have been worked.[25] In the Palen mountains and Maria mountains between the Colorado and Mohave deserts, there are extensive deposits of rock gypsum, and gypsite deposits are numerous.

Deposits are known to occur[26] in the counties of Fresno, Ventura, Kings, Monterey, Kern, San Luis Obispo, Santa Barbara, Los Angeles, San Bernardino, Riverside, and Orange. They are generally shallow and of the variety known as gypsite, although there are some extensive exposures of rock gypsum, as at Tecopa and in the Palen and Maria mountains.

Gypsum has been quarried in Fresno county, at Coalinga and Mendota; Kern county near Fellows, Mohave, McKittrick, and Bakersfield; Los Angeles county at Palmdale and Castaic; Monterey county, King City; Riverside county, Corona; San Bernardino county, Amboy; and Ventura county, Fillmore.

The more important gypsum beds of Colorado are found along the eastern part of the Rocky mountains.[27] At Loveland

Colorado the gypsum is interbedded with siliceous limestones and red marls. It varies from seven to twenty-eight feet in thickness and is compact and of a drab-gray color.

Near Morrison on Bear creek are local beds of unknown thickness, while at Deer creek, eight miles southeast of Morrison, they are twenty feet thick. A gypsum bed is conspicuous in the Garden of the Gods, near Colorado City, and at Canyon on the Arkansas. There are important deposits of gypsum in southwestern Colorado, to the east of the La Sal mountains, in the area drained by the Rio Dolores.

The gypsum quarried at Loveland analyzes from 92 to 99 per cent hydrous calcium sulphate and its age is Permian.

In 1919, gypsum was calcined at Arkins, west of Loveland and at Portland. It was quarried at Stone City in Pueblo county for use in Portland cement.

R. D. George[28] describes important deposits which occur in Larimer, Jefferson, Douglas, El Paso, Pueblo, Fremont, Custer,

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25Stone and others, Gypsum Deposits of the United States: U. S. Geol. Survey, Bull. 697, 1920.

26Stone, R. W., Gypsum Products, their Preparation and Uses: Technical Paper, 155, Bureau of Mines, p. 51.

27Siebenthal, Bulletin 285, U. S. Geol. Survey, pp. 401-404. Stone, R. W., Technical Paper 155, Bureau of Mines, p. 53.

28George, R. D., Gypsum Deposits of the United States: U. S. Geol. Survey Bull. 697, pp. 87-94, 1920.

Huerfano, Chaffee, Park, Rio Blanco, Garfield, Eagle, Pitken, Montrose, San Miguel and Dolores counties.

Gypsum has been reported in Florida from time to time, and a brief description of the best known occurrence was given by Florida Dr. David T. Day in the 20th Annual Report of the United States Geological Survey, Part 6. In a personal letter to the writer Dr. F. H. H. Calhoun gives additional information in regard to the Florida occurrence.

"This deposit is evidently formed from springs. It lies on the surface of the ground in masses from 6 to 12 feet deep; in other places of the area it is covered by an overburden in places as deep as 3 feet, the deposit itself in this situation being from 3 to 7 feet in thickness.

The composition of the gypsum is rather variable; in some places it is nearly pure gypsum and in other places it contains as high as 22½ per cent calcium carbonate. The material is in form of powder, in some places grading into a more granular structure.

This deposit is probably the same one visited by Dr. Day, but he evidently did not see the best exposures. The material first appears in Sec. 23, T. 20, R. 21, as a huge mound from 6 to 10 feet thick. It has an average length of 150 yards and an average width of 60 yards.

North of this large deposit, which occurs on what is known as Soapstone Island, the deposits become thinner and less continuous. It might be best described as a swell or saucer type.

This type continues for some 200 yards and then gradually gives place to the type of deposit on Bear Island described by Day. The deposits on Bear Island consist of isolated mounds of gypsum from 6 to 100 feet in diameter and probably average 3 to 4 feet in thickness. I estimate that the deposit on Soapstone Island contains about 35,000 tons, the adjacent deposit about 70,000 and that on Bear Island probably as much, but so scattered as to make quarrying difficult. I found very little evidence that these mounds were connected under the surface.

Further north about 5 miles east of Inverness more deposits are found, but in these the type is different. It lies beneath the surface covered with an overburden from a few inches to several feet in thickness. The deposit itself, I believe, would not average more than 3 feet and is not continuous. This deposit extends south some 2 or 3 miles."

Gypsum occurs in Washington county,[29] Idaho, in the bluffs

[29]Burchard, E. F., Mineral Resources of U. S., 1910, p. 13.

overlooking Snake River, about ten miles northeast of Hunting-
Idaho ton, Oregon, which is the nearest town. Short tunnels and prospect pits have shown that the material consists of lenticular masses of rock gypsum banded with grayish and greenish material, possibly chloritic, and indicate thicknesses ranging from six to twenty feet or more. The hill slopes are too steep and there is too much stripping necessary to render extensive open quarrying practicable, but the material can be obtained by mining. A railroad that connects with the Oregon Short Line at Huntington passes down the Oregon side of Snake river within 2,000 feet of the gypsum outcrop, and near enough for the rock to be carried across the river on an aerial cableway. The deposits here apparently are of the same series that occur on the Oregon side of Snake river, a few miles farther south. The Washington county gypsum deposits are held by the Northwest Gypsum Plaster Company of Huntington, Oregon.

Iowa Gypsum deposits of Iowa in Webster county about Fort Dodge and at Centerville in Appanoose county are fully described in Chapters IV and V.

Kansas possesses highly important beds of rock gypsum, and
Kansas a number of deposits of gypsite, or secondary gypsum. The area in which gypsum is found appears on the map shown in Plate XIII of the publication cited below.[30]

The more important centers are the Blue Rapids area, the Gypsum City area, and the Medicine Lodge area, as pointed out by Grimsley.[31]

From an examination of a map of west central United States with the gypsum deposits indicated thereon, it will be seen that if the northeast line of the Kansas deposits is extended it will strike the Fort Dodge area in Iowa, and if it is continued to the southwest it will strike the extensive deposits of Canadian river in Oklahoma and Indian Territory and Texas.

The Kansas gypsum is of Permian age, the beds in the northern part of the state belonging to the lowest portion of the Permian, while those farther south are higher. Both gypsum and gypsite are found within the state, the former in very extensive

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30U. S. Geol. Survey Bull. 223, p. 54; also Bull. 697, Pl. XVII, p. 112.

31Gypsum Deposits of the United States, U. S. Geol. Survey Bull. 223. See also Bull. 697, pp. 112-120.

beds and presenting very favorable conditions for development. Near Blue Rapids the bed is nine feet thick; near Gypsum City six to fourteen feet; at Dillon eighteen feet and in the Medicine Lodge area from three to twenty feet. The quality of the gypsum is good, and certain brands of plaster of Paris made in Kansas are well received for the finer uses by the building trade.

Gypsite is found at a few points. It is generally found in low ground in areas limited to a few acres, and in thickness from three or four feet to eighteen feet. Gypsite makes an excellent wall plaster with less expense for treatment than in the case of rock gypsum and for this reason Kansas gypsite beds have been extensively developed, but many of the deposits have been exhausted, and each year more reliance is placed on the rock gypsum deposits for the maintenance and expansion of the industry.

According to Stone[32] thick beds of gypsum have been encountered in deep drill holes in Louisiana at St. Charles, Calcasieu Parish, associated with sulphur, and at Pine Prairie, St. Laudry Parish. Gypsum occurs also at Rayburn's salt works, Bienville Parish.

Louisiana

The gypsum of Louisiana is not developed and on account of its position and the salts and minerals that are associated with it, there is little likelihood of its becoming important economically.

In connection with the oil domes in Louisiana extensive deposits of gypsum occur but under conditions that render it improbable that they will ever be of economic importance. These deposits are considered in Chapter III, in connection with the origin of gypsum deposits.

The principal gypsum areas of Michigan are[33]: (1) in the vicinity of Grand Rapids near the western side of the Lower Peninsula, and (2) at Alabaster, north of Saginaw bay on Lake Huron.

Michigan

The deposits occur in a formation which outcrops around the interior coal basin. At Grand Rapids there is an

32Gypsum Industry in 1913, U. S. Geol. Survey, Mineral Resources of United States.

33Stone, R. W., Gypsum Products, their Preparation and Uses; Bureau of Mines, Technical Paper 155, p. 55.

upper ledge six feet thick separated by one foot of shale from a lower ledge twelve feet thick; about forty feet below the latter bed there is a twenty-foot bed of gypsum and a few feet above this thick bed another deposit several feet thick, making four beds which have been utilized. Several thinner beds are not used. At Granville, five miles southwest, two ledges eleven and fourteen feet thick are separated by four feet of limestone. The gypsum is very pure and is taken from quarries and underground workings.

At Alabaster an extensive exposure of gypsum twenty-three feet thick has been worked back from its original outcrop on the shore of Lake Huron for more than a quarter of a mile, the quarry now being very large. A ten-foot bowlder-clay cover is stripped and the rock is blasted from a horseshoe-shaped face. The bottom of the quarry is about fifteen feet above the lake level. Several thin beds underlie the quarry within a depth of ninety feet. Gypsum has been found in a number of wells in northern Arenac county and southeast Ogemaw county; in Mackinac county near Point Aux Chenes, seven miles west of St. Ignace, and in the vicinity of St. Martin's bay.

Seven plants were operated in 1921 in Michigan, six being near Grand Rapids and one at Alabaster.

Montana

Developed gypsum beds occur in Montana in Cascade, Jefferson and Carbon counties. According to W. H. Weed[34] the gypsum occurs interbedded in a series of red and green shales with limestones carrying Mississippian fossils. The rocks have been folded by mountain forming uplifts and lie at steep angles, or more nearly horizontal a mile or more away from the mountains.

Deposits are reported near Millegan in Cascade county, and have been mined intermittently at Riceville and Goodman. The gypsum at these points is not continuous but occurs in lenses and in places contains clay and sandstone partings.[35]

In 1898 gypsum was quarried and milled near Monarch, but the mill was burned in 1900, and not rebuilt. Near Kibbey there

[34] Weed, W. H., Gypsum Deposits of the United States: U. S. Geol. Survey Bull, 223, p. 74; Bull. 697, pp. 131-138.

[35] Stone, R. W., Gypsum Deposits of the United States: U. S. Geol. Survey Bull. 697, p. 132.

is a good body of gypsum but it is located several miles from the railroad.

In Fergus county the gypsum bearing formations completely encircle the Big Snowy mountains, and beds of good material occur. Near Heath, where the United States Gypsum Company has prospected extensively, gypsum fourteen to sixteen feet thick is reported. A considerable area is underlain with an eight foot gypsum bed. At Hanover gypsum occurs at the top of the Carboniferous section. A seven foot bed is worked by the Three Forks Portland Cement Company, while thinner beds occur in the same locality.

In Jefferson county a small deposit has been developed just east of Lime Spur, by the Three Forks Portland Cement Company for use in its mill at Trident.

In Carbon county a ten foot bed at Bridger was developed for use in a plaster mill at that point but the mill has been idle for some years.

N. H. Darton[36] reports three beds of gypsum, five, sixty and fifty feet thick in the Red Valley on the Crow Indian Reservation. They are fifteen miles from a railroad and therefore remain undeveloped.

Other deposits are reported in Madison county and at Hunters Hot Springs on Yellowstone river.

The more important gypsum deposits in Nevada occur in two widely separated areas,[37] one in the western part and one in the southern part of the state.

Nevada

The western area lies in Humboldt, Washoe, Lyon and Mineral counties. The southern area lies in Clark and Lincoln counties. In both areas the gypsum is of exceptional purity and for that reason it has been developed to some extent, for shipment to rather remote points. Quarries are in operation at Lovelock, Mound House, Ludwig and Arden, and plaster mills are operated at Moapa and Arden. Considerable quantities are shipped to cement mills in adjoining states.

36Darton, N. H., Geology of the Big Horn Mountains: U. S. Geol. Survey, Prof. Paper 51, p. 38, 1906.

37Jones, J. C., Gypsum Deposits of the United States: U. S. Geol. Survey Bull. 697, p. 139, 1920.

New Mexico

Very extensive beds of exceptionally pure gypsum occur in New Mexico. In at least sixteen counties workable deposits have been found.[38]

On account of their remoteness from important markets these beds are not extensively developed. The gypsum of the Manzano group begins in northcentral New Mexico and thickens southward. These beds probably are Jurassic in age and the gypsum occurs in massive beds reaching a thickness of 100 feet. In the northern part of the state, above the Wingate sandstone and overlain by a thin bedded sandstone, a thick bed of gypsum outcrops on the sides of the Nacimiento and Landia mountains.

In Otero county, west of Alamogordo, wonderful white gypsum sand hills are found. They extend twenty-eight miles from north to south and in width range from six to fifteen miles. These deposits are ten to thirty feet high with an average thickness of twenty feet. Much of the material is snow-white. The origin of these gypsum hills is considered in Chapter III.

In 1919 mills were in operation at Acme, Chaves county; and Oriental, Eddy county. From time to time attempts have been made to develop the gypsum sands near Alamogordo, but transportation difficulties have proved too great to be overcome.

New York

The rocks of the Salina stage of the upper Silurian, which contains the workable gypsum of New York,[39] have for many years been studied along a belt extending without interruption from Albany county on the east to the Niagara river on the west, and thence into Ontario.

The Salina in New York is largely made up of shales. In the upper shale beds gypsum occurs in abundance, while salt is found in the middle of the series. An impure limestone caps the shales in the central and western part of the state while irregular bands of limestone occur within the shales. Except for a few feet near their base the shales are without fossils.

Underneath an argillaceous magnesian limestone known as the Bertie, which extends from Niagara river to Fayetteville, or somewhat beyond the center of the state, lies the Camillus

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[38]Darton, N. H., Gypsum Deposits of the United States: U. S. Geol. Survey Bull. 697, p. 161, 1920.

[39]Gypsum Deposits in New York, by D. H. Newland, New York State Museum, Bull. 143, 1910.

shale in which are found the workable beds of gypsum. These shales contain no fossils though one or two species have been found in thin bands of interlayered limestones. The gypsum deposits are seamed with shales which divide them into separate beds. The gypsum is present in regularly stratified beds which range from a few inches to five feet or more in thickness. It occurs in well defined lenses. The edges of these lenses have been broken by erosion and solution so that often large isolated masses of gypsum are found.

Small and irregular masses of gypsum are found in Herkimer and Madison counties but at present they are of no economic importance. Onondaga county contains important beds which are developed in the vicinity of Fayetteville and Jamesville. In Cayuga county the Salina series is well represented but the gypsum, while present in quantity, is low-grade, showing only eighty per cent hydrous lime sulphate.

Farther west, in Seneca and Wayne counties, the gypsum continues to be of low grade and is not abundant. Core drilling in Ontario county has shown beds of gypsum of good quality, but no developments of consequence have resulted.

The Bertie limestone covers the shales and gypsum in the next county to the west, Livingston, and there are no outcrops of gypsum and its presence would have to be determined by drilling.

In Monroe county gypsum of value is confined to the single township of Wheatland but within this area there are important developments in the vicinity of Wheatland.

Decidedly the most important developments in the state are in Genesee county, about the town of Oakfield, and just across the county line to the east, in Niagara county, about the town of Akron. Within this area some of the most important mills in the country are located. The gypsum that is worked is limited in thickness, averaging four feet, but is of good quality and is well located with reference to important markets and transportation. In 1921 New York ranked first in the production of gypsum. Two mills were located at Fayetteville where gypsum hauled from neighboring quarries was ground for agricultural purposes. The Cayuga Gypsum Company in Cayuga county, prepared crude gypsum for use in Portland cement and in agriculture. In Monroe county important plaster mills are located at Garbutt and Wheatland. The most important area is the Oakfield-Akron district in Genesee county, where four very large plaster mills furnish the greater portion of the state's output of gypsum. Up to 1920 approximately 9,000,000 tons had been mined in the state, approximately 7,000,000 tons having been taken out since 1890.[40]

Newland states[41] that "developments within recent years indicate that deposits of high-grade rock (over 90 per cent) are quite limited and are particularly confined to the western section of the Salina formation, in Erie and Genesee counties. Contrary to the opinion frequently expressed, the deposits do not extend to any great distance to the south of the outcrop on the dip of the formation, but thin out or change to the anhydrous condition as they reach a depth of more than 100 feet. The gypsum thus is the result of surface conditions which prevail through a very restricted horizon. This feature, together with the thinness of the bed indicates a rather meagre supply of the higher-grade material in western New York."

The gypsum beds of Ohio that are of commercial importance are found in Ottawa county, on the north and south shores of

Ohio

Sandusky bay. The beds north of the bay are near the town of Port Clinton, while those south of the bay are within two miles of Castalia. The beds range in thickness from three to seven feet. They belong to the Monroe formation of the Silurian system.

Professor Edward Orton[42] gives the following typical section:

		Feet
Drift clays, level of bay, 8 feet below surface		12-14
No. 1.	Gray rock carrying land plaster	5
	Blue shale	½
No. 2.	Bowlder bed carrying gypsum in separate masses, embedded in shaly limestone	5
No. 3.	Main plaster bed	7
	Gray limestone in thin courses	1
No. 4.	Lowest plaster bed, variable	3-5
	Mixed limestone and plaster, bottom of quarry, water enters here in quantity	

"The beds are not even and horizontal but are found in waves or rolls, the summits of which rise five to eight feet above

40Newland, D. H., and Leighton, H., Gypsum Deposits of the United States: U. S. Geol. Survey Bull. 697, pp. 187-217, 1920.

41Mineral Industry, McGraw-Hill Book Co., Vol. xxviii, p. 333.

42Geol. Survey Ohio, Vol. 6, p. 698.

the general level. Sections like the one given here will yield 50,000 tons of plaster to the acre.

The bed marked No. 1 in the section is a mixed deposit of shale and plaster that has hitherto been rejected but which has recently been found fully available for grinding into a dark colored land plaster. It has been lost by erosion in much of the territory already worked, and is not commonly counted among the valuable resources of the quarry.

No. 2 is one of the interesting divisions of the section. Scattered through the calcareous shales, there are balls of gypsum, concretionary in form and probably in character, varying in diameter from six to twenty-four inches. For a long time it was thought that they were of inferior value, and they were ground into land plaster, but recently it has been found that the present product of the quarries can be derived from these same plaster balls. The gypsum yielded by them when they have been carefully freed from their shaly envelopes proves to be of the whitest and purest sort, such as is used as terra alba."

Bownocker[43] states that "although the area underlain by gypsum is large, it seems probable that the deposit is too thin or at too great depth to be mined except along or near the lake shore west of Sandusky, and even there only two comparatively small areas have been actually tested."

In 1919 three mills were in operation, two at Gypsum, and one at Port Clinton. The mill at Castalia has run intermittently. Although the deposit of gypsum at that point is good, water conditions in the mine are difficult to overcome.

The gypsum of Oklahoma is Permian in age and is found in the "Red Beds," which extend from Texas through western Oklahoma into Kansas. The mineral is found in beds of rock gypsum which in places reach a thickness of sixty feet, and in the form of gypsite.

Oklahoma

The gypsum beds occupy three areas:

1. A line of gypsum hills resulting from the outcrop of the Blaine formation. Here, according to Linder,[44] three beds occur, the Shimer, the Medicine Lodge and the Ferguson. The gypsum is selenitic in all three beds, and the texture coarsely crystalline. The gypsum belt extends from the north across

[43]Bownocker, J. A., Gypsum in Ohio; U. S. Geol. Survey Bull. 697, pp. 218, 219.

[44]Linder, L. C., Gypsum Deposits of the United States: U. S. Geol. Survey Bull. 697, p. 225.

Harper, Woods, Major and Blaine counties, and dies out in Canadian county in the central-western portion of the state.

2. The important deposits in the second area occur in Custer and Washita counties. Here the gypsum is of the massive rock form and in places reaches a thickness of fifty feet. The area extends into Dewey county on the north and into Caddo, Grady, Comanche and Stephens counties to the south, but in these counties the deposits are of limited quantity and doubtful value. Considerable gypsite has been worked out in Caddo county, and an undeveloped deposit of some size is reported near Indianapolis.

3. The third area lies in the extreme southwestern portion of the state in Beckham, Greer, Jackson and Harmon counties. Here well defined beds occur, and at some places four and five beds, most of them of considerable thickness, are found. In addition gypsite deposits, particularly in Jackson county, are of considerable value.

The quantity of gypsum in Oklahoma is very great and it is developed to a considerable extent though the distance of the deposits from important markets is a serious handicap.

In 1919 mills were located at Southard, Eldorado, Homestead, Cement and Acme.

Oregon

Near the middle point of the eastern boundary of Oregon gypsum is developed on a ridge which forms the divide between Burnt and Snake rivers. The mineral occurs in lenses ranging from ten to forty feet thick. Some of these lenses are composed of white crystalline gypsum of good quality, while others are of doubtful value on account of impurities.[45] A mill has been erected at a point named Gypsum.

Gypsite is reported to occur in Crook county, where it is said to be more than fifteen feet thick and to require no stripping.

Pennsylvania

No gypsum deposits of commercial importance occur in Pennsylvania but in the deep well at Erie gypsum in considerable quantities is reported in the Salina formation just below the 1700 foot level.[46]

Important and fairly accessible beds of gypsum occur in the

[45] Stone, R. W., Gypsum Deposits of the United States: U. S. Geol. Survey Bull. 697, p. 236.
[46] Geol. Survey of Ohio, 4th Series, Bulletin 18, p. 414.

Black Hills, South Dakota. The structure of the Black Hills is that of a great dome, with the older crystalline rock in the center and more recent strata tilting away from the central mass. The Spearfish formation, which is probably of Triassic age, forms a ring around the Black Hills and gypsum is present at most places in this formation.[47] The gypsum ranges in thickness from a fraction of an inch to thirty feet. Two thick beds of gypsum occur near Minnekahta, with several beds from two to six feet in thickness. Between Minnekahta and Hot Springs gypsum outcrops as far east as Erskine station. Gypsum has been milled in the vicinity of Black Hawk, Rapid City and Hot Springs, though the mills at the latter points are not now in operation. The mill now operating at Black Hawk is using gypsite as raw material. From Tilford to Sturgis gypsum outcrops almost continuously and at Sturgis the bed is ten feet thick.

South Dakota

At present in addition to the mill at Black Hawk, a mill utilizing both rock gypsum and gypsite is in operation at Piedmont.

The gypsum deposits of Texas that have, up to the present time, been developed commercially, occur in connection with clays, sands and limestones of Permian age, which lie east of the Staked Plains in Texas and extend northward from the Texas and Pacific Railway across Oklahoma and Kansas.[48] The gypsum for the most part occurs massive and in beds varying from a few inches to twenty feet in thickness. They extend over a very considerable area and the total amount of gypsum available is almost beyond computation. In the same region occur extensive deposits of gypsite which are extensively developed.

Texas

In addition to the Permian deposits of Northern Texas there are others which Dumble regards as of equal, if not greater extent and value. These occur between the Guadalupe mountains and the western scarp of the Staked Plains in the valley of Pecos river. The Castile gypsum outcrops in a belt between the Delaware mountains and Rustler hills which has an average

47Hutton, C. H., Gypsum Deposits of the United States: U. S. Geol. Survey Bull. 697, p. 240, 1920.

48Mineral Industry, Vol. IV, pp. 375-380.

width of fifteen miles. It is of the massive white granular variety. Locally selenite is abundant. Its thickness ranges from sixty to over three hundred feet.

Large deposits of gypsum occur in the Malone mountains, which lie just south of the Southern Pacific line between El Paso and Sierra Blanca.

Another, and a rather remarkable occurrence of gypsum is found in the southern coastal region of Texas, in the neighborhood of Falfurrias. Here occur extensive deposits of gypsite and the most extensive beds of massive selenite that have ever been discovered. The thickness of the deposit is unknown, but Dumble reports it as over 1000 feet thick. This deposit seems to be related, as to origin, to the salt and oil domes of the coastal plains, with which extensive beds of gypsum are often found. The gypsum deposits in the vicinity of Falfurrias are within a reasonable distance of transportation. The terminus of the San Antonio and Arkansas Pass Railroad is only six miles away, and Sarita on the St. Louis, Brownsville and Mexican Railroad is only fourteen miles distant.

The remarkable deposits of gypsum encountered in deep drilling in the salt and oil domes of southeastern Texas are referred to on page 125, in Chapter III. Gypsum 600 feet thick was found at Spindletop and an equal thickness at High Island. In 1919 two mills were operating at Acme and one at Plasterco.

There are several important gypsum deposits in central and southern Utah.[49] The most important development is at Nephi, where a fully equipped mill secures its raw material from a highly inclined ledge of gypsum 400 feet high and 250 to 300 feet thick. At Levan in Juab county a somewhat similar deposit was utilized several years ago, but the mill at present is not in operation.

Utah

Gypsum outcrops almost continuously from Nephi southward in Sevier valley and at Sigurd in Sevier county two mills are in operation. At least three beds, somewhat broken by erosion and faulting, occur in this locality. Their thickness ranges from ten to fifty feet.

[49] Stone, R. W., and Lupton, C. T., Gypsum Deposits of the United States: U. S. Geol. Survey Bull. 697, p. 261, 1920.

Stone[50] describes an interesting deposit of gypsum in Millard county as follows: "About eight miles west of Fillmore gypsum occurs in deposits of three types—gypsiferous clay, gypsum sand, and loose crystals. The gypsiferous clay covers an oval area approximately three by five miles in extent. Gypsum sand dunes occur in two areas, one of them a mile long and a third of a mile wide, the other an irregular area approximately half a mile square. Mounds of loose small crystals cover an area two miles long and half a mile wide." These accumulations of wind blown material are remarkably pure and contain about 450,000 tons.

Other important but undeveloped gypsum deposits are found in Iron county where a bed 200 feet thick outcrops for several miles. In Emery and Wayne counties along the west side of the San Rafael Swell there are extensive beds of good rock gypsum. In Washington county several beds of gypsum, from five to fifteen feet in thickness, occur.

Virginia

A very restricted area in Washington and Smyth counties, in southwest Virginia, contains extensive deposits of gypsum that are commercially of considerable importance, and are of more than ordinary interest from a scientific point of view. The gypsum is associated with shales and limestones of Mississippian age and is found only near the point of contact of these rocks with a great overthrust fault which has brought Cambrian dolomite over the Lower Carboniferous strata. This fault, according to G. W. Stose,[51] has been traced through into the Rome fault which he states has been shown to have a displacement of five miles at Rome, Georgia. The gypsum occurs in huge masses of irregular shape and in various positions, surrounded by red and gray shales. Enclosed in the gypsum are irregular masses of dolomite and shale.

The peculiar nature of the deposit has given rise to a great deal of divergent speculation in regard to the origin of the gypsum and the salt which is in places associated with it. Eckel[52] attributed them to ordinary salt pan conditions. Stose regarded them as secondary deposits formed by ascending waters moving

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[50]Stone, R. W., Gypsum Deposits of the United States: U. S. Geol. Survey Bull. 697, p. 268, 1920.

[51]Stose, G. W., U. S. Geol. Survey Bull. 530, p. 20.

[52]Eckel, U. S. Geol. Survey Bull. 213, p. 406.

along the fault, which dissolved gypsum and salt disseminated through shales and limestones of the Mississippian formation.

Two gypsum mills are in operation in Virginia and the state is fourth in its annual output of gypsum. Its importance as a gypsum producing center lies in the fact that gypsum is not found in any other state in the southeast.

The gypsum of the Bighorn Basin, Wyoming, was described by C. A. Fisher[53] in 1905, and more recently by C. T. Lupton, D. D. Condit and R. W. Stone.[54] Beds of workable gypsum occur in the upper part of the Chugwater formation, and about Wyoming one thousand feet stratigraphically lower down, in the Embar formation. The beds differ in thickness and number, and evidently were not deposited in continuous sheets but rather as lenses in isolated bodies of water along the margin of a former sea. At one point in the Chugwater formation the gypsum appears in a single bed ranging from forty-two to seventy-four feet in thickness, while at other points from six to eight relatively thin beds are exposed. Gypsum of the Chugwater formation is found near Stucco, Graybull, Hyattsville, Tensleep, Bigtrails, Thermopolis, and on Kirby creek.

In the Laramie district, according to C. E. Siebenthal,[55] the heaviest developments of gypsum rock are found along the foot of the north slope of Red Mountain. He gives the following section taken from this locality:

	Feet
Red gypsum rock nearly pure	6
Red shale	35
Gypsum	3
Red shale	10
Gypsum	4
Reddish shale	55
Banded gypsiferous limestone	5
Red sandy shale	88
Gypsum, massive	67
Fossiliferous limestone	1

This basal limestone is everywhere crowded with fossils which represent only a few species and are of Upper Carboniferous age. A mile south of Red Buttes station a bed fifteen feet thick has been quarried since 1890. At Laramie extensive deposits

53Contributions to Economic Geology, U. S. Geol. Survey Bull. 285, p. 313, 1905.

54Stone, R. W., Gypsum Deposits of the United States: U. S. Geol. Survey Bull. 697, p. 295. 1920.

55Siebenthal, C. E., Contributions to Economic Geology; U. S. Geol. Survey Bull. 285, pp. 404-406, 1905.

of gypsite have been developed. Branson describes the gypsum in the Lander region[56] as ranging from a few inches to forty feet in thickness and maintaining a thickness of a few feet for long distances along the outcrop. The thick deposits in some localities extend for a mile, and contain only a few partings.

Other deposits are reported from the Rawlins uplift, Freezeout Hills, Grand Canyon of the Platte, Black Hills, and Medicine Bow, Shirley, Seminoe, Ferris, Rattlesnake, Bighorn, Absaroka, Prior, Wind Run, Gros Ventre and Salt Creek mountains.

In 1919 two mills were in operation at Laramie and a third at Red Butte. A small mill at Basin, Big Horn county, calcines limited amounts of plaster for the manufacture of gypsum blocks. These blocks are all used locally and on account of the semi-arid climate, have proved satisfactory for exterior walls.

GYPSUM IN CANADA

The deposits of gypsum in Canada are very extensive and valuable. Many of them are at or near tide water and therefore come in direct competition with American gypsum along the coast. The accompanying map, Plate IV, shows the location of Canadian deposits and the districts that are under development.

The provinces producing gypsum, in the order of their production are Nova Scotia, New Brunswick, Manitoba and Ontario.

Canadian production by provinces for the year 1912 is given below:

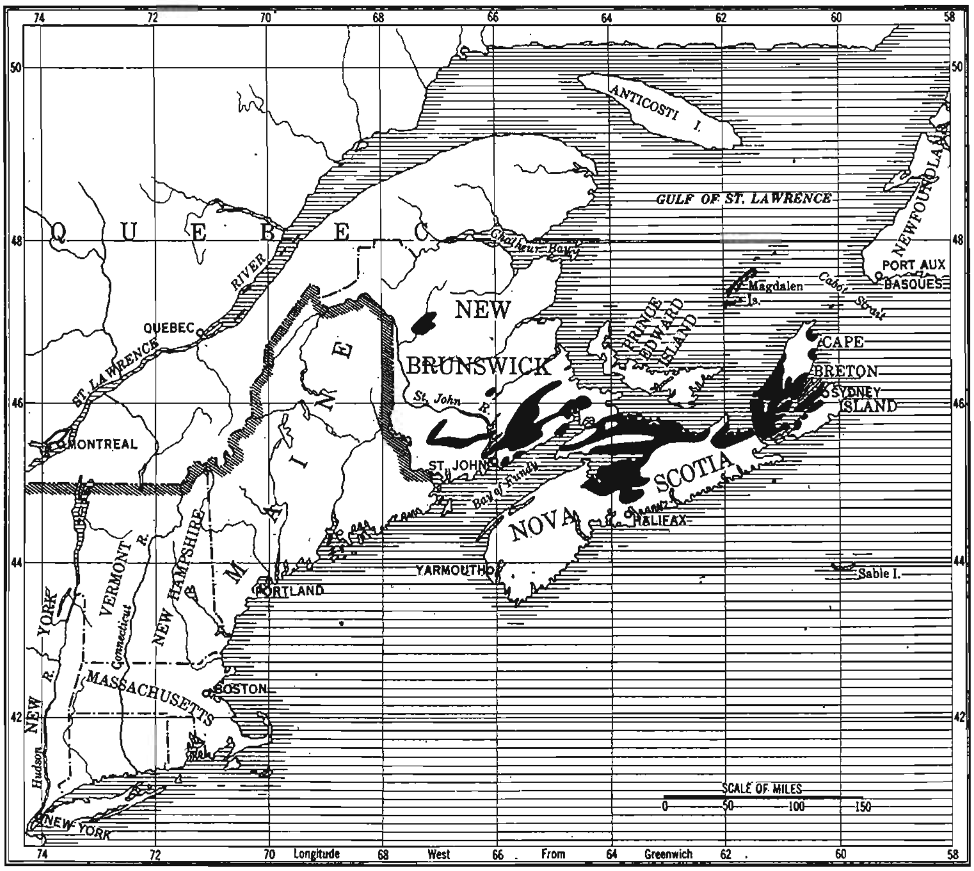
	Tons
Nova Scotia	376,082
New Brunswick	82,757
Manitoba	66,500
Ontario	53,119

Canadian production in 1920 was as follows:

Nova Scotia	260,661
New Brunswick	49,405
Ontario	74,707
Manitoba	45,371

The production in 1920 was restricted by the high ocean freight rates that prevailed during that year, which interfered

56Bull. Geol. Soc. America, Vol. XXVI, No. 2, p. 222.



Map showing the gypsum bearing formations of Nova Scotia and New Brunswick. Gypsum is present only in limited portions of these areas, shown as black on the map.

with the normal movement from the maritime provinces to American coast cities.

In Nova Scotia extensive deposits of economic importance are found in the following districts or counties[57]: Inverness and Victoria; Gypsborough and Antigonish; Pictou, Halifax and Colchester; Hants; and Cumberland. The gypsum is found in beds, associated with anhydrite and belongs to the Lower Carboniferous series. Some of the beds have a thickness of 100 feet.

Nova Scotia

Extensive gypsum beds occur in New Brunswick, and furnish large quantities of alabaster from which the higher grades of plaster of Paris are made. As in Nova Scotia, the gypsum belongs to the Lower Carboniferous measures. The principal deposits are found in the south of the province in the counties of King, Albert, and Westmoreland. In the northern part of the province there is a single occurrence in Victoria county.

New Brunswick

In Ontario beds of the same age and character as those in New York occur and have been developed to some extent, at York and other points in the vicinity of Grand river. The bed is four and one-half feet thick. While the bed extends over a considerable area the amount of water that is encountered at many points is a serious hindrance to development.

Ontario

In the province of Quebec gypsum occurs in the Magdalen islands, in the Gulf of St. Lawrence, and is like the Nova Scotia gypsum in age and physical characteristics. The principal deposits of economic importance are on Grindstone, Altright, Amherst and Entry islands.

Quebec

Manitoba possesses several deposits of gypsum. In the vicinity of Lake St. Martin exposures occur throughout an area of eight square miles. A mill has been erected at this point. In the southern part of the province, about eighteen miles east of Dominion City, a deposit of pure white gypsum is reported to have been found by drilling, at a depth of 325 feet. Gypsum occurs in the province of Alberta, at Bear Rock Mountain, a few miles west of Fort Norman.

Manitoba

In British Columbia, about twenty miles north of Kamloops

57Gypsum in Canada, by L. H. Cole, Canada Dept. of Mines, No. 245.

and on the east bank of Thompson river, a large deposit can be traced for a long distance along the mountain side. Another extensive deposit occurs about eleven miles east of Grand Prairie. Gypsum deposits have been developed near Merrett, a town on a branch of the Canadian Pacific Railway.

British Columbia

The following quarries are operated in the Maritime Provinces of New Brunswick and Nova Scotia by American capital for the furnishing of raw gypsum to American mills[58]:

Newport Plaster, Mining & Manufacturing Co. (Ltd.), Avondale, Nova Scotia, J. B. King & Co., New York.
Wentworth Gypsum Co. (Ltd.), Wentworth, Nova Scotia, J. B. King & Co., New York.
Hillsborough Plaster Quarrying & Manufacturing Co. (Ltd.), Hillsborough, New Brunswick, J. B. King & Co., New York.
Rock Plaster Corporation, Walton, Nova Scotia, Rock Plaster Corporation, New York.
Newark Plaster Co., McKinnon Harbor, Nova Scotia, Newark Plaster Co., Newark, N. J.
Albert Manufacturing Co., Hillsborough, New Brunswick, Newark Plaster Co., Newark, N. J., interests and others.
Windsor Gypsum Co. (Ltd.), Newport Station, Nova Scotia, Higginson Manufacturing Co., Newburgh, N. Y.

Shipments from these quarries constitute practically all of the raw gypsum imported in the United States.

The following quarries are operated by Canadian capital for Canadian use only:

Windsor Plaster Co. (Ltd.), Windsor, Nova Scotia.
Iona Gypsum Co. (Ltd.), Iona, Cape Breton, Nova Scotia.
Ontario Gypsum Co. (Ltd.), Caledonia and Carson, Ontario.
Manitoba Gypsum Co. (Ltd.), Winnipeg, Manitoba.

Following is a list of manufacturing plants operating in Canada:

Small mill at Windsor, Nova Scotia, operating but one kettle for a local market.
Iona Gypsum Co. (Ltd.), at Brador Lakes, Cape Breton, Nova Scotia, a two-kettle plant, shipping its product locally and to points on St. Lawrence river.
Albert Manufacturing Co., Hillsborough, New Brunswick, affiliated with the Newark Plaster Co., Newark, N. J., United States. A four-kettle plant, which ships plaster of

58Statement of J. C. Seguine, representing the firm of J. B. King & Co., at Tariff hearings in Washington on January 11, 1921.

Paris in barrels to a limited extent to points on the Atlantic seaboard, the major portion of its output being for Canadian consumption.

Ontario Gypsum Co. (Ltd.), Caledonia, Ontario. It supplies raw gypsum largely to Canadian cement plants. It also supplies calcined gypsum for the manufacture of gypsum blocks to the Ebsary Gypsum Co., (an American-owned corporation) for Canadian consumption only.

Manitoba Gypsum Co. (Ltd.), Winnipeg. Output distributed in Canada.

None of the foregoing plants (data on Manitoba Gypsum Co. lacking) manufacture plaster board or plaster block.

MEXICO, CUBA AND SOUTH AMERICA

Mexico

According to Manuel Rangel[59] gypsum occurs abundantly in the Cretaceous formation of Banderas Campana and the Sierrita Hills of the Mapimi districts. What is called "gypsum" (geso) in Tejamen, Avilez, San Jose des Canas, Mezquital and other places is only lime carbonate having the appearance of limy alabaster.

In a personal letter which accompanied two samples of gypsum, one of which contained considerable sulphur, two Mexican localities were discussed as follows:

"The darkest sample comes from a deposit in the vicinity of Iguala (a station of the Cuernavaca Branch of the Mexican Central R. R.). The other two are from a deposit near Axochiapam, a station on the Matamoros Branch of the Interoceanic R. R.

Both deposits are practically inexhaustible, but the exploitation of them is not cheap on account of their distance from the railroads. We get the gypsum from Iguala at $5.00 Mex. Cy. per ton (2,240 Lbs.) f.o.b. at Iguala and the freight from Iguala to Mexico City is $4.00 per ton."

Gypsum and sulphur occur at Conejos, north of Torreon. The sulphur is separated by melting with steam and both minerals are utilized.

South America

Gypsum in abundance is reported in Argentine, in the Cordilleras near Aconcagua,[60] but its inaccessibility renders it of no commercial importance.

Cuba

According to the American Consul General at Havana the most extensive deposits in Cuba and the only ones exploited to date are in and around Caibarien. Other deposits are reported near Matanzas.

59Eng. and Min. Jour., July 30, 1921.
60Dammer u. Tietze, Die Nutzbaren Mineralien, Vol. II, p. 78.

GYPSUM IN EUROPE[61]

Remarkably pure white gypsum in large quantities occurs in the Hartz mountains, in rocks of Permian age (Zeckstein formation). Important producing localities are Osterode, Nord-Germany hausen, Sangerhausen, Stoller, Ellrich and Ilfeld. In Thuringia gypsum in commercial quantities occurs at Eisenach, Erfurt, Altenstein and in the neighborhood of Oberellenbach. The gypsum in Thuringia belongs to the lower Trias. Figure 6 shows a quarry in a deposit at Krolpa.

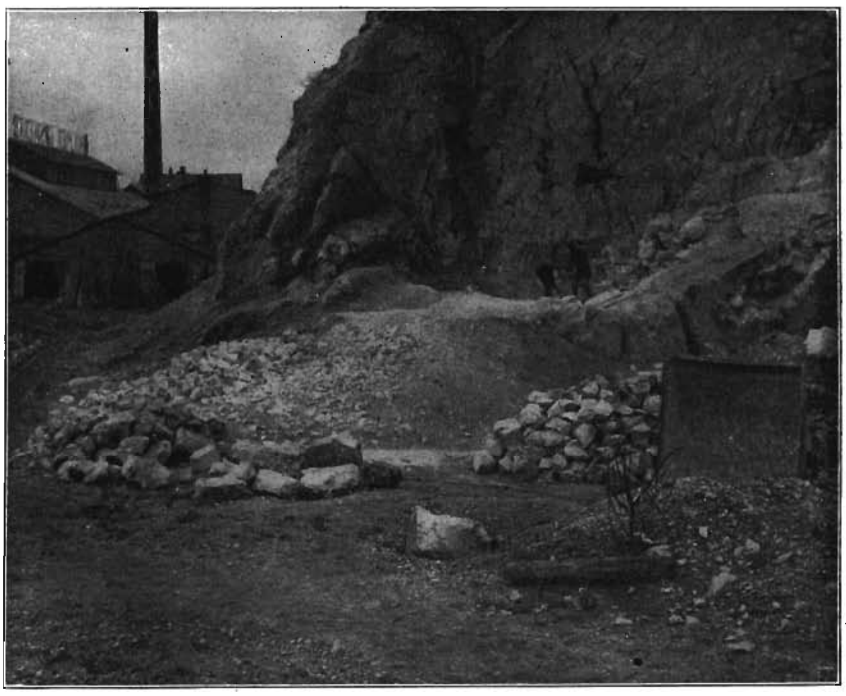


FIG. 6.—Gypsum quarry at Krölpa, Germany.

Gypsum of Triassic age occurs in Saxony in the vicinity of Eisleben and deposits of the same age are found at Luneburg, Segeberg, Lübtheim and Sperenberg. In Hesse gypsum of Triassic age occurs at Stottunheim and Reichelsdorf, and the extensive deposits along the Neckar river are of the same age. In Alsace gypsum of upper Triassic age occurs at Bergheim, Reichenweier, Balbronn and Waltenheim.

61Die Nutzbaren Mineralien, Dammer und Tietze, II.

In Wurtemberg, Triassic gypsum is extensively developed at Grailsheim and occurs at a number of other points. In the Bavarian Alps gypsum occurs at Tegersnee, Langgries, Oberau, Partenkirchen, Fussen, Pfronten and Hohenschwangau.

Gypsum in large quantities occurs about Salzburg, Austria, and at Groden in Tyrol. In Czecho-Slovakia, Kaaden is an

Austria important locality, and in the Carpathians, Wieliczka. The Vienna basin, in the Bruhl district, is productive, as are certain points in Siebenburgen.

Gypsum is found at Bex and Ehendingen in Aargau, Switzer-

Switzerland land, the last point yielding fine alabaster. There are extensive gypsum quarries near Ponterliers.

The Paris basin of France has long been famous for its gypsum and for gypsum products as is shown by the fact that

France calcined gypsum is everywhere known as plaster of Paris. The most important producing points in this basin are Mont Martre, Pantin, Belleville, Samois and Enghein where the gypsum occurs in three horizons interbedded with clay. The upper bed of gypsum is the most extensive and usually the thickest, reaching sixty-five feet at Mont Martre. The gypsum of the Paris basin contains lime carbonate up to 10 or 12 per cent.

The more important gypsum deposits of England occur in Cumberland, Nottinghamshire, Staffordshire, Derbyshire, and

England Westmoreland. The gypsum in these localities is of Upper Triassic age. Gypsum occurs also in Sussex and Lincolnshire. The British plaster mills are located in the towns of Newark, Nottingham, Carlisle and New Biggin.

The gypsum of Russia is of Devonian, Permian, Triassic and Tertiary ages. In the province of Archangel it occurs near the

Russia mouth of Pinega river; in the province of Livland near Adsel, Palzmar, Treppenhof, Schoneck, Allasch, Pullandorf, Stubbensee, Kengeragee, Schlockhof, Kemmen and in Pawasser. The central gypsum region extends from Stubbensee and Riga, through Stopinshof, Kengeragge, Dahlen and Kuchholm, in a southerly direction to Kurland. The most important producing points are Stopinshof and Pawasser. The gypsum occurs in beds which on account of bituminous content are yellow to dark blue in color. The thickness of the beds averages from three to five feet, and in places is as much as seven feet. In the province of Kurland gypsum is found in the neighborhood of Schlampen, Ekkendorf, Tackum, Randen, Leuten, Weggen, Eckhof, Goldengen, Appriken, Kalnezeem, and in the vicinity of Schonber, Baldohin and Dunshof. In the province of Pleskauski the gypsum industry is extensively developed at Dubniki and Drosdowa. A number of other localities are mentioned by Dammer and Tietze,[62] who refer to an article by Sodoffsky (in Zeitschrift fur prakt. Geol., 1904, 411).

Spain Spain possesses valuable gypsum deposits in Catalonia, Aragon and Andalusia, the last named province producing alabaster.

Italy The mountains of Tuscany yield gypsum in the vicinity of Castellina and Chiusdino. It occurs in lenses of white or agate-like banded alabaster. Gypsum occurs included in limestones of the Upper Triassic at Cornocchio, Roccastrada, and Chiauciano. It occurs also in connection with sulphur springs at San Fillippo and Campiglio d'Orcea. Gypsum is found in connection with the sulphur deposits of Girgenti.

GYPSUM IN ASIA

Gypsum in great masses is reported at Anna, India, and in Asiatic Turkey. It is quarried in the vicinity of Damascus and Aleppo,[63] and in Turkestan, near Krasnowodsk.

Persia In Persia and the Near-East, gypsum is in many cases associated with oil seeps.[64] On the north of the road from Mossul to Bagdad oil seeps from gypsum beds at a number of points. Oil springs exist in the vicinity of Kifri about 150 kilometers northwest of Bagdad, where beds of gypsum yield quantities of salt, sulphur and petroleum. On the Euphrates in the vicinity of Hit the natives by crude methods obtain about 2500 tons of asphaltic oil a year from a series of gypsum beds in layers up to two meters thick intercalated with sandy clays. In western Persia, about 150 miles west of Shustas, seepages from

62Dammer u. Tietze, Die Nutzbaren Mineralien.

63Eng. and Min. Jour., Nov. 26, 1921.

64Edmund M. Speicher's review of "Die Turkisch-Persischen Erd oeloorkommen," by Schwerr, Published in Eng. and Min. Jour., Aug. 14, 1920.

beds of light yellow loam rich in sulphur and gypsum yield small quantities of oil.

China

Gypsum has been developed near Hankow, China. The raw material has for the most part been sold to Japanese for export.

GYPSUM IN AUSTRALIA

South Australia contains gypsum deposits of considerable magnitude. These occur in the hundred of Warrenben, at Marion Bay; in the hundred of Melville, on Yorke Peninsula; and in the hundred of Gordon, on the Murray Flats.[65]

The deposits at Lake Fowler, Yorke Peninsula, are of considerable extent and take the form of sand hills up to sixty and eighty feet in height. These hills are composed entirely of gypsum. The upper six to nine feet consist of fine "flour" gypsum, which differs from the American gypsite in its greater purity. Chemical analysis shows that it contains 43 to 44 per cent SO_3. The lower part of the hills consists of coarser material, locally called "seed" gypsum, which shows an equally good percentage of SO_3.

In the hundred of Warrenben, near Marion Bay, the gypsum is in the form of a lake deposit from six inches to four feet in thickness, and is free from overburden. In the winter months there is a considerable quantity of water in the lake and quarrying operations are confined to the summer when the lake is practically dry. The gypsum layer breaks clean from the limestone floor underneath it, which makes a good bottom for shoveling.

In the hundred of Gordon the gypsum occurs in a bed three or four feet thick, and is in the form of flour gypsum.

GYPSUM IN AFRICA

Africa

The pyramids of Egypt bear witness to the ancient use of gypsum as plaster, and the word alabaster is derived from a state in upper Egypt. At present gypsum is found at Wadi Gerrani, not far from Memphis, and in the vicinity of ancient Hermopolis. Recently a quarry has been opened about forty miles southeast of Alexandria. The bed differs in thick-

65South Australia Dept. of Chemistry, Bull. No. 7, 1917.

ness from one and one-half to nine feet and extends over a considerable area and is supposed to contain one and a half million tons.

In Tripoli, Tunis and Morocco there are numerous occurrences of gypsum, some of them of considerable extent. The age of the beds is reported as Triassic.

The cement factories of the Union of South Africa secure a scant supply of gypsum from irregular segregations in certain valleys in the arid districts of Natal and Orange Free State.[66] The output is about 100 tons a month, valued at £300.

THE GEOLOGICAL AGE OF THE MORE IMPORTANT GYPSUM DEPOSITS OF THE WORLD

FOREIGN	AMERICAN
PLEISTOCENE AND RECENT	
	Florida[1]
	Utah[2]
	(Dunes in Millard County)
	New Mexico[3]
	Alamogordo
	California[4]
	Lake deposits
PLIOCENE	
Austria[5]	
Wieliczka	
and	
Siebenbürgen	
MIOCENE	
	Idaho[6]
	California[7]
OLIGOCENE	
Transylvania[8]	
Carpathian Mts.	
Germany[9]	
Sperenberg	
France	
Montmartre[10]	
Upper Alsace[11]	

1. Calhoun, F. H. H., Mineral Industry for 1917
2. U. S. Geol. Survey Bull. 697, p. 269
3. U. S. Geol. Survey Bull. 697, p. 163
4. U. S. Geol. Survey Bull. 697, p. 58
5. Credner, Geologie, p. 699-700
6. U. S. Geol. Survey Bull. 697, p. 100
7. U. S. Geol. Survey Bull. 697, p. 84
8. Geikie, Text Book of Geology, 3d. Ed., p. 856
9. Credner, Geologie, p. 679
10. Credner, Geologie, p. 675
11. Dammer u. Tietze, II, p. 67

66So. Afri. Min. Jour., Aug. 10, 1918.

EOCENE

None

CRETACEOUS

Arkansas[12]
Colorado[13]

JURASSIC

Utah[14]
Sigurd
New Mexico[15]

TRIASSIC

Germany[16]
Hanover, Anstadt
Erfurt, Thuringia
Lothringen Neckar
Ellrich
England[17]
Devonshire
Russia[18]
Archangel
Tunis[19]

South Dakota[20]
Black Hills
Arizona[21]
Wyoming[22]

PERMIAN

Germany[23]
The Hartz
Stassfurt, Sperenberg
Austria[24]
South Tyrol
Russia[25]

Iowa[26]
Fort Dodge
Texas[27]
Kansas[28]
Oklahoma[29]
South Dakota[30]
Black Hills
Colorado[31]
Larimer and Douglas counties
Wyoming[32]
Big Horn Mts.

12. U. S. Geol. Survey Bull. 697, p. 57
13. U. S. Geol. Survey Bull. 697, p. 87
14. U. S. Geol. Survey Bull. 697, p. 268 and 275
15. U. S. Geol. Survey Bull. 697, p. 163
16. Dammer u. Tietze, II, p. 66
17. Giekie, Text Book of Geology, 3d. Ed., p. 866
18. Dammer u. Tietze, II, p. 58
19. Dammer u. Tietze, II, p. 70
20. U. S. Geol. Survey, 21st Ann. Report, Part IV (Darton)
21. U. S. Geol. Survey Bull. 223, p. 101
22. U. S. Geol. Survey Bull. 697, p. 295
23. Credner, Geologie, pp. 503-511
24. Giekie, Text Book of Geology, 3d. Ed., p. 853
25. Giekie, Text Book of Geology, 3d. Ed., p. 853
26. Iowa Geol. Survey, Vol. XII, p. 111
27. 3d. Ann. Report Texas Geol. Survey, p. 212
28. Geol. Survey of Kansas, Vol. V
29. U. S. Geol. Survey Bull. 697, p. 4
30. U. S. Geol. Survey, 21st Ann. Report, Part 4 (Darton)
31. U. S. Geol. Survey Bull. 697, p. 87
32. U. S. Geol. Survey Bull. 223, p. 86

New Mexico[33]
Mesa Lucero
East of Socorra
Phillips Hills
Sacramento Mts.

CARBONIFEROUS

Colorado[34]

MISSISSIPPIAN

Michigan[35]
Alabaster
Grand Rapids
Nova Scotia[36]
Virginia[37]
Montana[38]
Carbon county
Madison county
Iowa[39]
Centerville
Nevada[40]
Lovelock

DEVONIAN

Russia[41]
Baltic Provinces

SILURIAN

Russia[42]
Baltic Provinces

New York[43]
Ohio[44]
Michigan[45]
St. Ignace
Iowa[46]
Grinnell

CAMBRIAN

India
Punjab Salt Range[47]

33. U. S. Geol. Survey Bull. 697, pp. 164-170
34. U. S. Geol. Survey Bull. 697, p. 87
35. Geol. Survey of Michigan, Vol. V (1881-93), Part II, pp. 14-30
36. Min. Resources of Canada, 1897, pp. 105-111
37. U. S. Geol. Survey Bull. 697, p. 285
38. U. S. Geol. Survey Benton Folio, p. 6
39. U. S. Geol. Survey Bull. 697, p. 8
40. U. S. Geol. Survey Bull. 697, p. 147
41. Geikie, Text Book of Geology, 3d. Ed., p. 789, also Dammer u. Tietze, II, p. 68
42. Geikie, Text Book of Geology, 3d. Ed., p. 789
43. N. Y. Geol. Survey, Vol. III, No. 15, p. 550
44. Geol. Survey of Ohio, Vol. VI, pp. 691-702
45. Geol. Survey Mich., Vol. I (1869-73), Part III, pp. 913-915
46. Iowa Geol. Survey, Vol. XXI, p. 581. Gypsum at depth of 1010 to 1030 feet.
47. Geikie, Text Book of Geology, 3d. Ed., pp. 737-739

CHAPTER III

ORIGIN OF GYPSUM AND ANHYDRITE

Early students of the subject, including Dana, who wrote particularly of the gypsum in New York, believed that gypsum was generally derived from limestone by the action of sulphurous waters resulting from the oxidation of pyrite and other sulphides. After Ochsenius, in 1877, published the results of his studies of sea water, belief gradually centered about the idea that most gypsum deposits have been formed directly from sea water under conditions favorable to evaporation, which resulted in a concentration of its saline contents.

Early opinions

More recently A. W. Grabau[68] pointed out difficulties in connection with the direct evaporation theory. E. B. Branson[69] came to the support of the direct evaporation, or "salt pan" theory, with a "modified bar" hypothesis, which assumed a second or inner basin in which the brine reached the gypsum depositing stage. The views of these writers are presented somewhat at length later in the chapter.

In 1910 F. L. Hess[70] grouped gypsum deposits in four classes.

Recent classifications

1. Efflorescent deposits
2. Periodic lake deposits
3. Interbedded deposits
4. Veins

R. W. Stone[71] adopted a similar classification for gypsum deposits derived from solution. He further adds

5. Deposits produced by alteration
6. Deposits produced by disintegration and mechanical reaccumulation.

The classification given below, based upon origin, will be followed in this chapter.

1. Deposits, generally disseminated, and seldom of economic

68Grabau, A. W., Principles of Stratigraphy, p. 350; also Bull. Geol. Soc. America, Vol. 24, pp. 496-498.

69Bull. Geol. Soc. America, Vol. 26, p. 235

70Hess, F. L., Reconnaissance of the Gypsum Deposits of California, U. S. Geol. Survey Bull. 413, 1910.

71Gypsum Deposits of the United States, Bull. 697, U. S. Geol. Survey, 1920 importance, formed directly by evaporation of sea water.

2. Concentrations, accomplished by moving waters, of gypsum disseminated through sediments.
    a. in inland lakes
    b. on the surface
        1. by springs
        2. as efflorescence,
            concentrated further by winds and streams
    c. in fissures, cavities, and as replacements.
3. By alteration
    1. of carbonates
    2. of anhydrite
    3. of calcium-bearing minerals in igneous rocks by ascending sulphides.

DEPOSITION FROM SEA WATER

Gypsum is deposited with other salts on the evaporation of sea water, which contains three and one-half per cent of mineral matter of the following sorts and percentages:[72]

		Per cent Total Salts	Per 1000 Parts Water
Nature of salts in sea water	Chloride of sodium	77.758	27.213
	Chloride of magnesium	10.878	3.807
	Sulphate of magnesium	4.737	1.658
	Sulphate of calcium (gypsum)	3.600	1.26
	Sulphate of potassium	2.465	.863
	Carbonate of lime	0.345	.123
	Bromide of magnesium	0.217	.076
		100.000	35.000

The order of deposition of salts from sea water with increse in density of the brine is shown in the following table compiled by Grabau:[73]

72Encyclopedia Brittanica.

73Principles of Stratigraphy, p. 349

TABLE SHOWING THE SEPARATION OF SALTS FROM SEA WATER

Density of the sea water or of the mother liquor at 12.5°C. (Baume scale)	Specific gravity (after Clark)	Volume after evaporation and crystalization. Liters	SEPARATION AT THE SUCCESSIVE DENSITIES IN GRAMS								
			Sesquioxide of iron, Fe_2O_3	Calcium carbonate, $CaCO_3$	Calcium sulphate, $CaSO_4 \cdot 2H_2O$	Sodium chloride, NaCl	Magnesium sulphate, $MgSO_4$	Magnesium chloride, $MgCl_2$	Sodium bromide, NaBr	Potassium chloride, KCl	Total precipitated
1	2	3	4	5	6	7	8	9	10	11	12
1.0258	1.0258	1.0000	....	....	....	....	....	....	....	....	....
1.0506	1.0500	0.5330	0.0030	0.0642	....	....	....	....	....	....	0.0672
1.0820	1.0836	0.3160	....	trace	....	....	....	....	....	....	trace
1.1067	1.1037	0.2450	....	trace	....	....	....	....	....	....	trace
1.1304	1.1264	0.1900	....	0.0530	0.5600	....	....	....	....	....	0.6130
1.1653	1.1604	0.1445	....	....	0.5620	....	....	....	....	....	0.5620
1.1786	1.1732	0.1310	....	....	0.1840	....	....	....	....	....	0.1840
1.2080	1.2015	0.1120	....	....	0.1600	....	....	....	....	....	0.1600
1.2208	1.2138	0.0950	....	....	0.0508	3.2614	0.0040	0.0078	....	....	3.3240
1.2285	1.2212	0.0640	....	....	0.1476	9.6500	0.0130	0.0356	....	....	9.8462
1.2444	1.2363	0.0390	....	....	0.0700	7.8960	0.0262	0.0434	0.0728	....	8.1084
1.2627	1.2570	0.0302	....	....	0.0144	2.6240	0.0174	0.0150	0.0358	....	2.7066
1.2874	1.2778	0.0230	....	....	....	2.2720	0.0254	0.0240	0.0518	....	2.3732
1.3177	1.3069	0.0162	....	....	....	1.4040	0.5382	0.0274	0.0620	....	2.0316
Total precipitated			0.0030	0.1172	1.7488	27.1074	0.6242	0.1532	0.2224	....	29.9762
Remainder in mother liquor			....	....	....	2.5885	1.8545	3.1640	0.3300	0.5339	8.4709
Sum total of salts			0.0030	0.1172	1.7488	29.6959	2.4787	3.3172	0.5524	0.5339	38.4471

The following diagram (figure 7) presents in a general way the relation of deposition to density of salts common to sea water.

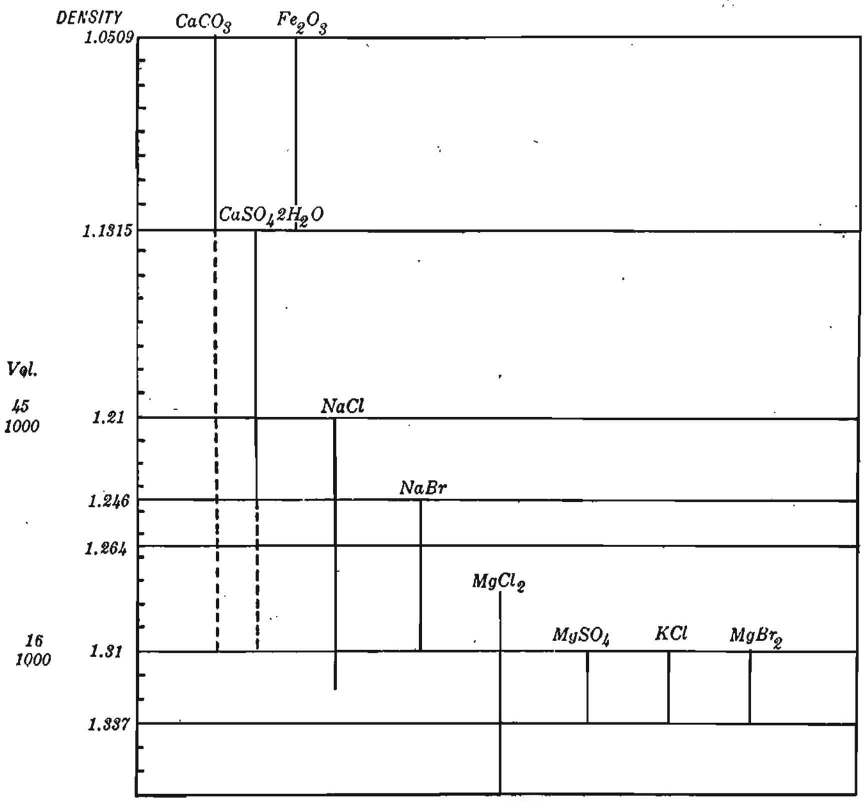


FIG. 7.—Sketch showing the order of precipitation of salts from sea water with increase in density.

Deposition of salts from sea water

Three-fourths of the gypsum is deposited between the densities of 1.1315 and 1.21, or when the volume of the water has been reduced from 80 to 92 per cent. The remaining one-fourth of the gypsum is deposited with the salt but constitutes so small a part of the whole that the commercial value of the salt is not appreciably lowered. The normal order of deposition on evaporation from sea water, beginning with the first precipitates, which will occur, of course, at the bottom of the deposit, is:

1. Limestone with limonite ($CaCO_3$ and $2Fe_2O_3{-}3H_2O$).
2. Gypsum $CaSO_4 . 2H_2O$ (with a small percentage of limestone).
3. Sodium chloride (common salt) NaCl (with some gypsum and traces of limestone).
4. The bitter salts ($MgSO_4$, $MgCl_2$, NaBr).

When deposits resulting from the evaporation of sea water are under consideration attention is generally called to Karabugas gulf on the eastern border of the Caspian sea, by way of illustration. This gulf is separated from the Caspian by a long and narrow bar, save for a narrow and relatively shallow channel through which a stream of salt water from the Caspian constantly flows to compensate for the evaporation within the gulf. It is stated that this current carries 350,000 tons of salt into the gulf daily. The density of the water is, of course, steadily increasing and has already reached the point where certain salines are deposited. Gypsum crystals are formed near the margin of the gulf, while toward the center sodium sulphate is deposited, though only in the winter months, for at summer temperatures the water is not saturated as regards sodium sulphate. It is not saturated at any natural temperature for common salt, sodium chloride, and this substance remains in solution.[74] Two analyses of the salts contained in the waters of Karabugas gulf, quoted by Clarke, appear as A and B in the table below.

Karabugas gulf

	A	B	C
Cl	53.32	50.26	55.29
Br	.06	.08	.188
SO_4	17.39	15.57	7.69
CO_3	--------	.13	.20
Na	11.51	25.51	30.59
K	1.83	.81	1.10
Rb	.06	--------	--------
Ca	--------	.57	1.19
Mg	15.83	7.07	3.72
	Salinity 28.5 per cent	Salinity 16.39 per cent	Salinity 3.3 to 3.7 per cent

For purposes of comparison the mean of seventy-seven analyses of the salts contained in sea water collected by the Challenger Expedition appears under C.[75] Quoting Grabau[76] "This gulf further illustrates the enormous destruction of organisms due to the intense salinity, a destruction that would render all

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74 Clarke, F. W., The Data of Geochemistry: U. S. Geol. Survey Bull. 616, p. 166, 3d Ed. This gives reference to a number of original sources.

75 U. S. Geol. Survey Bull. 616, p. 123.

76 Principles of Stratigraphy, p. 354.

salt deposits of such a gulf highly fossiliferous. Andrussow calls attention to the large number of fish which are carried across the bar into the Karabugas, where they perish. Their carcasses float about as long as the water flowing into the gulf moves them, after which they either sink to the bottom or are driven onto the shore.

"Among other organisms killed in the saline waters of this gulf **Cardium edule** should be mentioned. This eurybaline organism abounded in the gulf before it reached the stage at which sulphates were deposited. The shells of this species occur in enormous numbers on the shores of the Karabugas."

Nile delta salt pans

Gypsum is deposited, according to Grabau,[77] in connection with natural salt pans in the Nile delta. These salt pans extend along the coast "and owe their salt to flooding from the Mediterranean and the rapid evaporation due to the desert climate of the coast. The salt is covered by wandering sand dunes, which when they reach a great thickness become filled through efflorescence with crystals of gypsum three to five cm. long. These unite into heads one to four meters broad and from one-half to one meter in thickness.

Red Sea salinas

"On the borders of the Red sea are a number of salinas. One west of Amfila Bay on the Abyssinian border lies below sea level, and is surrounded by a wall of gypsum. The streams flowing from the East Abyssinian mountains into this depression evaporate, adding their contribution to the saline deposits. At Allolebod, on the southern coast of the Red Sea, the deposits in the natural pans show regular interstratification by layers of gypsum similar to the annual rings of the Stassfurt salt. These layers mark the periodic inundations of the salt pans."

Difficulties of evaporating basin theory

The great thickness of some occurrences of gypsum and salt must be considered in connection with any theory offered to explain their origin. The combined series at Stassfurt amounts to more than 1000 feet and that at Sperenberg to more than 3000 feet. To yield even fifteen feet of gypsum, the average thickness in the Iowa field, an immense amount of water of the composition of ordinary sea water must have been evaporated. A cubic foot of gypsum weighs 140 pounds and the amount of gypsum in a cubic foot of sea water today is three-fiftieths of a pound, so that 2,333.3 cubic feet of sea water are required to yield one cubic foot of gypsum.

[77] Principles of Stratigraphy, p. 355.

If the sides of the containing basin were vertical the depth of the water necessary to produce fifteen feet of gypsum must have been 34,986 feet. If the average thickness of the Webster county gypsum be taken as fifteen feet, and the gypsum area regarded as thirty square miles in extent, nearly thirty trillions of cubic feet (29,270,220,000,000) of ordinary sea water must have evaporated in the deposition of the gypsum beds.

Branson's hypothesis

Branson[78] has proposed a "modified bar hypothesis" to account for thick deposits of gypsum free from salt. By this hypothesis he aims to supply the receiving basins with highly concentrated waters instead of normal sea water. He says, "In the drying up of a large interior sea the waters might come to lie in separate basins if the bottom were uneven. Evaporation over the full expanse of the interior sea might be rapid enough to decrease the depth and area in spite of the inflow of some stream, but when considerable areas of bottom had become exposed the total evaporation would have become less and the inflow nearer to the rate of evaporation. Assuming that isolated basins would be found, separated by low barriers and that the main streams would empty into the marginal basins, the inflow might be sufficient to cause these basins to overflow and supply the inner basins, that had no direct stream connections, with highly charged waters as fast as their own waters evaporated. As beds of gypsum 10 feet in thickness are widespread, a depth of water great enough to contain the salt of sea water evaporated to deposit them must be assumed, and the evaporation must not be carried beyond nine-tenths of the original amount if the salt is to remain in solution. The depth of a basin for 10 feet of gypsum would have to be at least 1400 feet and possibly 1500."

Branson accounts for beds of gypsum reaching great thickness, by supposing that currents shifted unconsolidated gypsum and deposited it in the deeper or quieter basins. He supposes that after the water has deposited its gypsum an inflow of water from one or more of the stream fed border basins causes the basin to overflow into a more remote basin where evaporation brings the water to the salt depositing stage.

Deposition of thick beds of relatively pure gypsum directly from sea water is attended with many difficulties. To secure such a result a considerable number of pecular conditions must

[78]Branson, E. B., Bull. Geol. Soc. America, Vol. 26, No. 2, June, 1915, p. 235.

be operative at the same time. There is no point on the earth's crust where all of the necessary conditions exist today. It is true that some gypsum is being deposited today from sea water. Cases have been cited as in Karabugas gulf; the Nile delta salt pans; and the Red Sea salinas. In all of these instances, however, the gypsum is very impure, or consists merely of thin bands or detached crystals scattered through silt.

If any extensive and practically pure beds of gypsum are to be regarded as direct deposits from sea water, some disposition must be made of the lime carbonate which is present in sea water. If sea water is evaporated in the laboratory the lime carbonate is deposited, partly before the gypsum and partly with it, as illustrated in figure 7.

The lime carbonate problem

E. B. Branson[79] points out that "if the waters were widespread in the beginning, about half of the limestone might be deposited over the wider area, as more than half of the $CaCO_3$ precipitates when the volume of sea water is reduced about fifty per cent." Branson states that he has not seen limestone immediately below the gypsum at any place in the Red Beds of Wyoming. There is no limestone immediately below the gypsum in Webster county, Iowa, though the lower six inches of the gypsum contains some calcium carbonate. A twenty foot bed of gypsum like that at Fort Dodge should have nearly a foot and a half of limestone below it if the evaporation all took place in a restricted basin.

It is probable that a considerable amount of the lime carbonate would be precipitated near the point where the water of the outer basin began to mingle with the denser brine of the inner basin. There would, however, be a considerable lime carbonate contamination throughout the basin.

The carbon dioxide of the atmosphere is an important factor influencing the solubility of calcium carbonate. This fact must be kept in mind in considering the deposition of gypsum directly from sea water. Julius Stieglitz[80] in a very interesting discussion entitled The Relations of Equilibrium between the Carbon Dioxide of the Atmosphere and the Calcium Sulphate, Calcium Carbonate, and Calcium Bi-

Stieglitz and atmospheric equilibrium

79Branson, E. B., Bull. Geol. Soc. America, Vol. 26, No. 2, p. 235, 1915.

80Stieglitz, Julius, in Contributions to Cosmogony and the Fundamental Problems of Geology, Carnegie Institute, p. 236, 1909.

carbonate of Water Solutions in Contact with It, concludes that for an ideal condition, if the natural waters of the earth were supposed to contain only lime salts, that is the sulphate, carbonate and bicarbonate, in equilibrium with the carbon dioxide of the atmosphere, then by evaporation they would deposit first, as is now the case, until the solution became saturated with gypsum, all the calcium carbonate in solution in excess of the amounts given in table 5 in columns 3 and 5; depending on the partial pressure of the atmospheric carbon dioxide. When the solution becomes saturated with gypsum this will, by continued evaporation, crystallize out, but no

TABLE 5

CO_2 atmosph.	$CaSO_4$ grams	$CaCO_3$ grams	$CaSO_4$ moles	$CaCO_3$ moles	$CaCO_3$ per cent
0.00003	2.07	0.006	0.0152	0.00006	0.30
.0003	2.07	.019	.0152	.00019	0.90
.003	2.07	.059	.0152	.00059	2.89

matter whether it is deposited in the same locality as, or in some other locality than, the first great deposit of calcium carbonate, the gypsum must inevitably be continuously contaminated with some calcium carbonate, varying from 0.3 to 2.85 per cent according to the partial pressure of the carbon dioxide in the atmosphere within the limits given.

Professor Stieglitz further continued his studies by considering the influence on the deposition of calcium sulphate, of the presence in the solution of other sulphates and of sodium chloride. He concludes

1. that if the natural waters of the earth were supposed to contain only lime salts, that is the sulphate, carbonate and bicarbonate, in equilibrium with the carbon dioxide of the atmosphere, and if the average partial pressure of carbon dioxide in the atmosphere were the same as at present (0.0003 atmosphere) by evaporation the gypsum would be precipitated with contamination of 0.9 per cent of calcium carbonate.

If the carbon dioxide were reduced to one-tenth the amount in the present atmosphere—a condition hardly conceivable—the gypsum would still be precipitated with contamination of calcium carbonate, though the amount would be reduced to 0.3 per cent.

If the carbon dioxide were increased to 10 times the amount in the present atmosphere, the calcium carbonate contamination would increase to 2.85 per cent.

2. The presence of other sulphates which might be found in sea water would increase the calcium carbonate contamination of the gypsum.

3. An increase of temperature, by decreasing the coefficient of absorption of carbon dioxide would possibly be a favorable factor in the formation of pure gypsum by evaporation of sea water. Such increase in temperature, however, would probably be associated with an increase in the amount of carbon dioxide in the atmosphere and as has been noted, an increase in the carbon dioxide content of the atmosphere means a rapid increase in calcium carbonate contamination of the gypsum.

4. The presence of large amounts of sodium chloride (about 8 to 25 per cent) would have a tendency to reduce the calcium carbonate contamination.

Professor Stieglitz calls attention to Usiglio's work on Mediterranean water where calcium sulphate began to be deposited when the water reached the density of 1.13, which corresponds to a chloride content of 17 per cent. This concentration, Stieglitz states, was reached in Cameron's experiments for solution 7, from which, going to solution 8, gypsum would be obtained with about 0.8 per cent of carbonate.

5. "Even if the great mass of an excess of calcium carbonate in a solution were deposited first in some other locality before the point of saturation for gypsum were reached, the requirements for equilibrium would be such as to hold carbonate in solution and to make the question of the place of deposit of the excess of carbonate in the first instance one of no moment."

As a result of Stieglitz' work it seems necessary to draw the conclusion that it is very unlikely that gypsum that contains less than nine-tenths of one per cent of calcium carbonate, was formed under salt pan conditions.

Inasmuch as there are many published analyses of gypsum which contain less than nine-tenths of one per cent of calcium carbonate it seems necessary to take such deposits out of the salt pan class, or else to suspect that the analyses were not made with sufficient care with reference to calcium carbonate. In some cases there is ground for suspecting the accuracy of the analyses. Recent analyses of the Fort Dodge, Iowa, gypsum, for instance, show sufficient calcium carbonate to permit the supposition that they were deposited from sea water, though earlier analyses had shown no carbonate.

Analyses of a great many interesting and important deposits remain, however, that record no lime carbonate, and unquestionably some of these analyses were carefully made and fairly represent the bed as a whole. This list of carbonate-free deposits contains those in

- Arizona
  - Douglas
  - Empire Mountain
- California
  - Amboy
  - Palmdale
- Florida
  - Penasoffkee
- Iowa
  - Centerville
- Kansas
  - Kling
  - Medicine Lodge
- Montana
  - Armington
  - Boulder
  - Great Falls
- New Mexico
  - White Sands of Alamogordo
- Oklahoma
  - Cement
  - Southard
- Utah
  - Levan
  - Nephi
- Wyoming
  - Red Buttes

Certain portions of the gypsum in Virginia and at Medicine Lodge, Kansas, contain lime and magnesium carbonate, while other portions seem to contain no carbonate.

DISSEMINATED GYPSUM

The preceding pages have been devoted to gypsum deposits, usually disseminated, resulting from the evaporation of seawater in more or less detached basins. There are other sources for the gypsum that is found in limited quantities in a great many sedimentary rocks.

Disseminated gypsum from connate waters

Grabau has called attention to the "connate" waters in sedimentary beds. He regards these oceanic waters, imprisoned when the sediments were laid down, as the chief source of material for saline deposits.

It is highly probable that along the shores of the ancient oceans gypsum was deposited more or less continuously, in small quantities, with all classes of sediments. Waves rolling up the beach saturate the sands with brine which later evaporates, leaving the salts. Beach sands today contain more or less salt and gypsum and the amount that they retain depends upon their protection from leaching. The salt leaches out readily, while considerable quantities of the gypsum may remain.

Much gypsum has been formed by the action of sulphurous waters circulating through sediments that contain calcium carbonate.

Disseminated gypsum by chemical reaction

The shales of nearly every geological horizon in numerous and widespread localities contain individual crystals and rosettes of selenite produced by the action of iron sulphate derived from the oxidation of pyrites, on lime carbonate. Selenite so derived is particularly abundant in the Mississippian, Pennsylvanian and Cretaceous shales.

CONCENTRATION OF DISSEMINATED GYPSUM

Waters flowing over or through sediments containing disseminated gypsum dissolve the gypsum and under certain conditions redeposit it in concentrated form. Arid regions present conditions favorable for such concentration. If the moisture of the region is sufficient to permit of intermittent streams, both the surface water and the springs feeding them will be heavily charged with salts. These streams, which may be perennial in their lower courses, generally empty into a detached basin.

The water of the river Jordan gives the following analysis:[81]

	PER CENT
Sodium chloride (common salt)	.35
Magnesium chloride	.03
Calcium chloride	.07
Calcium sulphate (gypsum)	.04
Water	99.50

81Bischof, Chem. and Phys. Geology, Vol. I.

The waters of the Dead Sea are largely the result of concentration by evaporation of this water. Quoting Bischof:[82] "In spring when the streams are turbid with the particles of carbonate of lime and clay, mere mechanical deposits take place, for at this period, when large masses of water are carried into the Dead Sea, and the saline solution is thereby diluted, while at the same time the evaporation is but slight, no common salt is deposited. During the ensuing warmer months the chemical deposition of common salt and carbonate of lime takes place. Should the stream become turbid at this season in consequence of continued rain, deposits are formed which contain a less amount of common salt. In this way there must arise a constant alternation of different irregular layers of greater or less thickness. All these layers must contain gypsum since in a water which contains so much chloride of magnesium as is present in the Dead Sea, gypsum as we shall subsequently see, is dissolved with difficulty."

The Dead Sea

Great Salt lake is but a remnant of the much larger Lake Bonneville, which was fresh and was drained by a stream flowing into Snake river. The streams flowing into Great Salt lake carry considerable quantities of mineral in solution, as is shown by the following table:[83]

Great Salt Lake

	A	B	C	D	E	F	G
Cl	2.68	32.36	35.54	34.76	5.38	23.21	13.73
SO_4	5.76	8.16	26.54	30.68	2.87	5.65	9.25
CO_3	52.68	21.53	2.67	trace	52.57	33.68	40.00
Na }	4.49	20.54	26.13	23.04	3.74	11.31	8.37
K }						4.16	4.19
Ca	23.69	10.12	7.59	10.26	24.19	16.05	18.19
Mg	6.86	4.76	1.53	1.26	7.15	5.94	6.27
SiO_2	3.84				3.69		
$AlFe_2O_3$		2.53			.41		
Total	100	100	100	100	100	100	100
Salinity, parts per million	185	637	892	1090	243	444	455

A. Bear river at Evanston, Wyoming.
B. Bear river at Corrine, Utah.
C. Jordan river at intake of Utah and Salt Lake canal.
D. Jordan river near Salt Lake City.
E. City Creek, Utah.
F. Ogden river at Ogden, Utah.
G. Weber run at mouth of canyon.

Clarke adds: "All of the waters tributary to Great Salt Lake, so far as they have been examined, contain notable quantities of carbonates, which are absent from the lake itself."

82Ibid, p. 397.
83Data of Geochemistry, U. S. Geol. Survey Bull. 616, p. 156.

The present salinity of the lake is high, the specific gravity being 1.1 and its saline content, varying with the seasons from 14 to 22 per cent, is distributed as follows, as shown in five analyses[84]:

Sodium chloride	90.7	79.1	65.9	81.3	80.5
Potassium chloride			14.1		
Magnesium chloride	1.1	9.9	8.9	6.7	10.3
Sodium sulphate	8.2	6.2	8.1	8.5	5.4
Potassium sulphate	.....	3.6		2.6	2.4
Calcium sulphate	.....	.6	1.5	.9	1.4
Chlorine (in excess)	.....	.6	1.5	.....	.....

In these analyses the absence or the very small content of calcium, both as sulphate and carbonate, is remarkable. Analyses of the fresh waters tributary to the lake show that the lake could accumulate its total content of calcium in eighteen years while the accumulation period for the chlorine would be 34,200 years[85]. Manifestly the lake is disposing of much of the calcium as fast as it is received. Deposits of tufa occur on the old Bonneville, Intermediate and Provo shore lines, on their weathered faces, and a few feet below their crests. It is absent in sheltered bays and most abundant on points that were especially exposed to wave action. Calcereous oölitic sands are now forming along certain parts of the shore of Great Salt lake "between the delta of the Jordan and Black Rock, where it constitutes the material of a beach, and is drifted shoreward in dunes."[86] Of the three important fresh water tributaries of Great Salt lake, the water of Utah lake is characterized by sulphate of lime, over 60 per cent of the total solids held in solution by it consisting of this salt, while the waters of Bear river and City creek are characterized by carbonate of lime."[87] Strictly speaking, in the last case, as commonly when carbonate of lime is in solution, the lime is in the form of the bicarbonate. During the process of aeration caused by the beating of the waves against the shore carbon dioxide is given off and the lime, reduced to calcium carbonate, is deposited.

The oölitic sands may be ascribed to the action of plants which have the power of withdrawing carbon dioxide from soluble calcium bicarbonate, which would cause the precipita-

84Gilbert, G. K., Lake Bonneville: U. S. Geol. Survey Monograph I, p. 254.
85Idem, p. 256.
86Idem, p. 169.
87Idem, p. 207.

tion of the insoluble carbonate.[88] Deposits of calcareous tufa and oölite are particularly abundant near the mouths of streams which convey carbonate of lime to the lake and possibly the lime carbonate is wholly withdrawn from the inflowing water before it has an opportunity to mingle with the more remote waters of the lake.

The Bessarabian coast of the Black Sea furnishes an example of salt deposits in bays slightly connected with the ocean and fed from the landward side by rivers. From the Danube to the Dnieper the rivers before emptying into the ocean expand into lakes which are separated from the sea by natural dams. Under ordinary circumstances the water flows into the sea through an opening in the dam, while during storms the water of the sea enters the lakes. Three of these lakes become partly dry every summer and deposit salt which in places amounts to a layer a foot thick.[89] This salt is used for commercial purposes. The calcium sulphate of the river water and of the sea water which is driven in during storms must also be deposited, but the quantity being small readily escapes notice.

The difficulties in the way of accumulations of practically pure gypsum in stream fed inland basins are, in general, the same that interfere with accumulations of gypsum from sea water. It is conceivable that differential solution might give rise to inflowing streams carrying no salt in quantity except gypsum. It is impossible, however, to cite instances where extensive beds of gypsum are today forming in this way.

Spring deposits

The gypsum deposits of Florida have been formed in recent geological time and according to R. W. Stone are due to the action of springs.[90] The great masses of gypsum found in the "domes" of Louisana and Texas are regarded by G. D. Harris[91] and some others as the work of water moving upward along fissures. It is supposed that the gypsum was originally disseminated through beds located below the present accumulations.

F. L. Hess in his report of the gypsum deposits of Cali-

88Russell, Lakes of North America, p. 76.

89Bischof, Vol. I, p. 392.

90Stone, R. W., Gypsum Deposits of the United States: U. S. Geol. Survey Bull. 697, p. 95, 1920.

91Bull. Louisiana Geol. Survey No. 7, 1908.

fornia describes a deposit of gypsum, sulphur and hydrocarbon, which is locally known as the "oil bubble".[92] He states that "the mound is formed by the evaporation of water carrying gypsum in solution and clay probably being brought to the place by winds. The excessive dryness of the surrounding country makes it seem probable that the water comes from a considerable depth, rising through the Tertiary gypsiferous sandstones."

According to G. W. Stose the gypsum deposits of Virginia were probably derived from calcareous-argillaceous sediments which contained disseminated gypsum. He believes that this gypsum was dissolved by underground waters which circulated along the fault that lies close to the gypsum deposits, and was later deposited in concentrated form at higher levels.

Deposits by ascending waters and seepages

The domes of the gulf coast are built up of immense masses of gypsum and salt, with which in some instances oil and sulphur are associated. Although there is diversity of opinion as to the origin of these domes many believe that the gypsum and salt have been deposited in the domes by waters moving upward along fault planes.

In Persia and the Near East gypsum is in many places associated with oil seeps.[93] The association of gypsum with oil and bituminous shales may be the result of the action of sulphur, which is usually associated with hydrocarbons; or it may merely indicate that the same seepage conditions that bring the oil to the surface have been instrumental in concentrating and depositing gypsum.

Satin spar veins

In many gypsum fields the associated shales and clays are banded with satin spar seams. These may follow the bedding of the clays or may run in various directions. These satin spar zones unquestionably are secondary concentrations. They occur in massive gypsum, and the gypsum of the Fort Dodge area shows, on careful examination, numerous fine bands of satin spar parallel to the bedding. From such zones of infiltration the gypsum has often crystallized, crowding back the surrounding clays until bodies of gypsum of considerable extent have resulted.

92Hess, F. L., U. S. Geol. Survey Bull. 413, p. 15.

93For a more complete report of occurrences of this nature see paper by the writer in Bull. Geol. Soc. America, Vol. 32, No. 4, pp. 385-394.

In many arid regions gypsum appears as an extensive efflorescence. The delicate crystals so formed are later broken off and heaped up by the winds till they form immense dunes, or gypsum hills. The best known deposits of this type are the "White Sands" of Alamogordo, New Mexico. Many millions of tons of remarkably pure gypsum occur in these hills, which would be of the greatest commercial importance if they were nearer to important markets. Similar deposits occur in Australia and in Utah.

Efflorescent gypsum deposits

Gypsum dunes

GYPSUM PRODUCED BY ALTERATION

Ochsenius published his conclusions in regard to deposition of salts from sea water in 1877. Previous to that time gypsum was generally regarded as an alteration product, derived from limestone. Sulphurous waters are abundant and their ability to convert limestone into hydrated lime sulphate has long been recognized. Numerous instances of gypsum deposits which have been formed in this way have been reported.

From limestone

An interesting case at Spatsum, British Columbia, is described by L. H. Cole[94]. Gypsum-bearing rocks occur on the hills forming the west bank of Thompson river. Cole says that "the surface material consists of badly disintegrated masses of mica schists, limestones and shales with frequent nodular lumps of white gypsum of varying size. After passing through this altered material, which has been highly recemented, the tunnel cuts through a band of very pure massive white gypsum which proved by analysis to be almost a theoretically pure gypsum. This band, however, was only 5 feet wide with very light gray or white highly altered hydro-mica schist together with some altered limestone for the hanging wall."

O. M. Knode of the United States Gypsum Co. visited the spot and found a tunnel forty feet long driven into a bed of crystalline limestone. The whole face of the tunnel was moist and slimy from a deposit of sulphur and gypsum. Analyses of the rock along the sides of the tunnel gave from 12 to 100 per cent gypsum.

Grabau[95] in his latest work, returns to the older view of Dana and ascribes the New York gypsum to the action of sulphurous waters on limestone.

94Cole, L. H., Gypsum in Canada, pp. 95, 96.
95Text Book of Geology, Part I, p. 246.

W. G. Matteson, in a valuable paper recently presented to the American Institute of Mining Engineers,[95a] reviews the earlier work in connection with salt dome structure and concludes that the domal materials were "deposited relatively near the surface directly from solutions of secondary origin and character." So far as the gypsum is concerned he says that "it appears most likely that the original domal materials consisted only of limestone, probably in the form of travertine, and salt, the gypsum being the result of the conversion of the limestone through the action of sulfuric acid and hydrogen sulfide-bearing waters and gases."

Gypsum from anhydrite

A. J. Rogers,[96] after reviewing the more important anhydrite deposits of the United States, arrives at the conclusion that many, if not most, of the important gypsum deposits have been formed by the hydration of sedimentary anhydrite. Some important anhydrite beds are probably not sedimentary, and Rogers' statement is rather broad. It emphasizes an aspect of the situation, however, that generally has been overlooked. The Virginia gypsum and the important deposits about Windsor, Nova Scotia, seem to have been derived from anhydrite. In the light of recent drilling Newland[97] is inclined to the opinion that the more important deposits in New York were originally anhydrite.

ORIGIN OF THE FORT DODGE GYPSUM

If the Fort Dodge gypsum is regarded as the residue left after the evaporation of a body of sea water, originally widespread but eventually concentrated within a few square miles, it is necessary to account for the absence of the limestone and salt that would be associated with gypsum precipitated by such a process. It is possible that after reaching the density required for gypsum deposition, some diversion took place and the water failed to deposit its salt. Such an interruption in the natural course of events would come if there were a great inflow of fresh water; if the brine by some change in surface elevation should be drawn off to deposit its salt elsewhere; or if an

95a Transactions American Institute Mining & Metallurgical Engineers, Vol. LXV, pp. 295-322, 1921.

96 School of Mines Quarterly, Columbus Univ., Vol. XXXVI, January, 1915, p. 141.

97 Mineral Industry, 1920, Vol. 28, p. 333.

oceanic connection should be established or an existing connection enlarged so that the brine would be diluted.

If salt were deposited at Fort Dodge it might easily have been removed by preglacial erosion. The absence of salt therefore is not in any way a definite factor in determining the origin of the gypsum.

The absence of limestone beneath the gypsum is more difficult to explain if the gypsum is regarded as the result of the direct evaporation of sea water. The earlier pages of this chapter make it plain that there should be a foot or two of limestone below the gypsum, since sea water that will deposit fifteen feet of gypsum necessarily contains enough lime carbonate to make a bed of this thickness. There is no limestone anywhere beneath the gypsum at Fort Dodge. The lower six inches of the gypsum contains lime carbonate in varying amounts, possibly up to 25 per cent. The gypsum itself contains from one to two per cent of lime carbonate. The amount of carbonate in the gypsum, however, is not sufficient to account for the lime carbonate in sea water of sufficient volume to deposit fifteen feet of gypsum though it is sufficient to satisfy equilibrium requirements.

It seems more probable that the Fort Dodge gypsum represents the concentration of gypsum by streams flowing over and through the St. Louis limestone and Coal Measure shales. Certain layers of the St. Louis limestone contain 2.46 per cent of gypsum while some gypsum is present in practically all of this limestone.[98] The Coal Measure shales about Fort Dodge abound in crystals of selenite as do the marls of the Ste. Genevieve. These limestones, shales and marls formed the surface of the region when the gypsum was deposited. On account of its solubility streams crossing these beds would readily dissolve the disseminated gypsum. See page resulting in efflorescence may have been a contributing factor. Some lime carbonate would be dissolved also. The greater portion of this probably was deposited locally as in the case, already cited, of the tufa deposits on the shores of Great Salt lake.[99]

98Iowa Geol. Survey, Vol. XII, p. 184.
99For further discussion of the origin of the Fort Dodge gypsum see Chapter V.

ORIGIN OF THE CENTERVILLE GYPSUM

The Centerville gypsum is associated with more or less anhydrite. The deposit is made up of remarkably pure gypsum; gypsum and anhydrite; and practically pure anhydrite. It resembles in these respects the well known gypsum deposits about Windsor, Nova Scotia. It does not occur in definite layers and there are no distinct laminae. The original mineral may have been anhydrite, and the hydration of that portion which is now in the form of gypsum may have taken place either before or after the overlying beds were laid down.

The published analyses of the Centerville gypsum show no calcium carbonate. The probabilities are that the anhydrite, which was later in part altered to gypsum, was formed by alteration of limestone.

ORIGIN OF ANHYDRITE

From solutions of rather high concentration of the more soluble salts, calcium sulphate is more apt to be deposited in the anhydrous form. If the temperature is somewhat high anhydrite instead of gypsum may be deposited from less saline solutions.[100] D. H. Newland interprets the work of Van't Hoff as follows:[101]

"Van't Hoff and his associates, in their experimental work on the minerals of the Prussian potash deposits, found that solutions of calcium sulfate, when evaporated in open containers, and therefore under atmospheric pressure, deposit gypsum or anhydrite according to the temperature reached at saturation. Up to 66° C. gypsum separates, above that limit anhydrite; however, if the solution contains other salts, the boundary temperature for gypsum-anhydrite will be lowered. In the presence of sodium chloride, anhydrite begins to form at 30° C. and the gypsum deposited below that temperature will, in contact with a solution saturated for sodium chloride, change into anhydrite. In the evaporation of sea water, the crystallizing point of anhydrite is 25° C.

"From these data, it appears that the deposition of gypsum and anhydrite at atmosphere pressures is not simultaneous, but each substance crystallizes during a separate range of tempera-

100See summary of the work of Van't Hoff and Meyerhofer, by Cameran, F. K., and Bell, T. M., Calcium Sulphate in Aqueous Solutions: U. S. Dept. Agr., Bureau of Soils Bull. 33, p. 9, et seq., 1906.

101From a paper by D. H. Newland, presented in September, 1921, at the Wilkes-Barre meeting of the American Institute of Mining Engineers.

tures, which is lower for gypsum than for anhydrite. Therefore, in the evaporation of marine and saline lake waters, which undoubtedly were the sources of most of the calcium-sulfate deposits, it would appear that the prevailing precipitate is likely to be anhydrite rather than gypsum, for such waters contain salts that must lower the boundary temperatures within the range of those ordinarily reached in dry climates."

If the figures given above are correct, a temperature of 77° F. (25° C.) for the gypsum solution at the time that saturation was reached, would result in a deposit of anhydrite instead of a deposit of gypsum, assuming that the solution was originally sea water.

In the preceding pages the difficulties in the way of direct deposition of either gypsum or salt from sea water have been discussed although the possibility of such direct deposition is admitted.

Newland further argues that on account of the increase in volume that accompanies the transformation of anhydrite into gypsum, pressure lowers the temperature of dehydration whenever the released water has a chance to escape. He draws the inference that gypsum becomes unstable under conditions of moderate temperature and permanent load, while anhydrite as is generally known is the unstable form under atmospheric pressure and average surface temperatures. He finds confirmation of his opinion that in many cases anhydrite must be regarded as the original mineral in the conditions existing in western New York. "Where the deposits may be followed from the outcrop under an increasing cover in the direction of the dip, anhydrite begins to appear at 150 feet or less and within the next hundred feet becomes the predominant mineral."

Newland's theory

According to J. A. Udden[102] extensive beds of anhydrite in Texas have been formed by the dolomitization of limestone, as a result of a reaction between magnesium sulphate in the circulating solutions and the calcium carbonate in the original sediment.

Udden's theory

102Udden, J. A., The Deep Boring at Spurr: Bull. Univ. of Texas, No. 363, p. 67.

CHAPTER IV

GENERAL DESCRIPTION OF THE IOWA GYPSUM AREAS

THE FORT DODGE AREA

Early geological work

Some of the earliest geological work undertaken in Iowa was carried on in Webster county. Des Moines river crosses the gypsum area and gives excellent exposures of the glacial drift and the underlying beds. Naturally the water courses determined the routes of the pioneer students of geology for they combined means of transportation with the best opportunities for observation. The position of the area in the state is shown in figure 8.

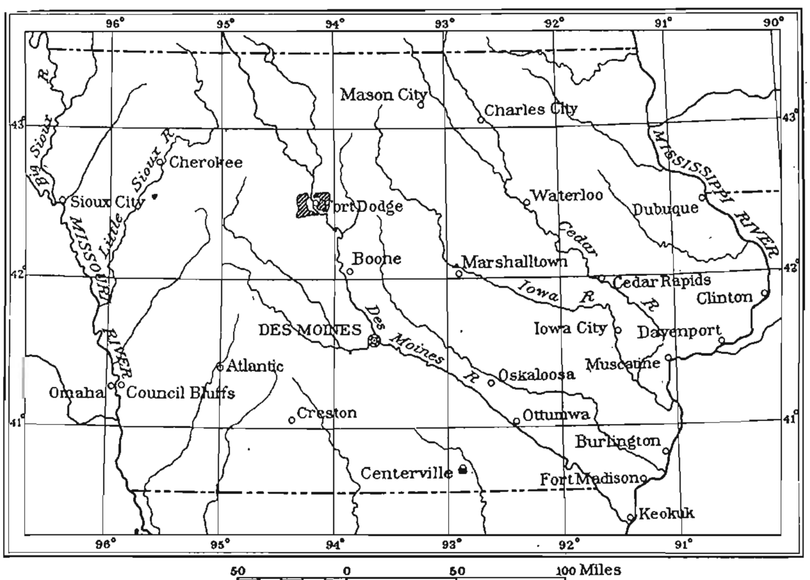

FIG. 8.—Map showing the location of the Fort Dodge and Centerville gypsum fields. Courtesy of U. S. Geological Survey.

Owen

In the year 1849 David Dale Owen[103] made a hurried trip up Des Moines river, noticed the gypsum in Webster county, made certain deductions in regard to its age and called attention to the abundance of the vegetation within the gypsum area.

[103] Geology of Wis., Iowa and Minn., p. 126, Philadelphia, 1852.

Worthen

In 1856 Worthen visited the region and came to the conclusion that the gypsum does not lie conformably on the Coal Measures.

Hall
McGee

James Hall[104] in 1858 and W J McGee[105] in 1884 investigated the stratigraphic relationships of the gypsum and contributed to the discussions in regard to its age.

White

Webster county was included in the investigations of C. A. White and in his annual reports of 1868 and 1870 he referred to its coal and gypsum.[106] He laid stress on the economic significance of the gypsum and urged that it be developed so that the state might furnish stucco and land plaster at least in quantities sufficient to meet its own requirements.

Keyes

In 1893 Charles R. Keyes[107] reported quite fully on the gypsum area. He considered the position and extent of the deposit and its stratigraphic relationships. He emphasized the value of the gypsum and described the quarrying and milling methods at that time in use. His opinion as then expressed, as well as his later views in regard to the age of the gypsum will be considered at some length in chapter V.

Wilder

In his report on the Geology of Webster county Frank A. Wilder[108] discussed somewhat at length the age and origin of the gypsum about Fort Dodge and devoted some time to the technique of the industry which had advanced considerably in the eight years that had elapsed since Keyes' report was issued.

Keyes' later papers

In recent years Keyes[109] has put forward the theory that the Fort Dodge gypsum is associated with faulting on a large scale. He ascribes its preservation and its rather abrupt termination on the north to this cause.

General location

The city of Fort Dodge lies nearly in the center of the Webster county gypsum field. Along Soldier creek, which roughly bounds the city on the north, are numerous outcrops of gypsum, while along both banks of the Des Moines, which runs through the city, historic exposures occur. Fort

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104Geology of Iowa, Vol. I, p. 142, 1858.
105Tenth U. S. Census, Vol. C., Building Stones, p. 258, Washington, 1884.
106First Annual Report, State Geologist, pp. 26-27, 1868; Second Annual Report, pp. 135-140, 1868; Geology of Iowa, Vol. II, p. 293 and pp. 254-256.
107Iowa Geological Survey, Vol. III, pp. 259-304, 1893.
108Iowa Geological Survey, Vol. XII, pp. 63-235, 1901.
109Keyes, Chas. R., Controlling Fault Systems in Iowa, Iowa Academy of Science, Vol. XXIII, pp. 103-112.

Dodge is located somewhat northeast of the center of the state, and is well supplied with railroads, which offer unusually good transportation facilities. The Fort Dodge mills can compete favorably with Grand Rapids, Michigan, in the Chicago markets. They are nearer Milwaukee, St. Paul, Minneapolis and Duluth than any other producing point. To the south they meet Kansas and Oklahoma competition in St. Louis, and the distance is somewhat greater than from Centerville. To the west, Omaha, Council Bluffs and Sioux City are nearer to Fort Dodge than they are to the gypsum mills in the Black Hills of South Dakota. It is not surprising that the Fort Dodge gypsum field has become one of the most important in the country.

Markets

The extent of the gypsum area must be determined by exposures along the Des Moines and its tributaries, by well records and by drilling. Throughout the region the mantle of glacial drift is heavy and contains many gravel beds which are excellent water pockets, and in consequence only a limited number of wells penetrate the drift and enter the underlying formations. Natural exposures of gypsum may be seen on the left bank of Lizard creek one-fourth mile above its mouth; at intervals for two miles along the lower course of Soldier creek; along Two Mile creek, and the little stream directly opposite whose course is followed by the interurban railway. The best known exposures are, of course, along the river, from the mouth of Soldier creek south nearly to the town of Kalo. Away from the streams the position of the gypsum beds must be determined by prospect holes and by well drilling. Areas close to the railroad and near the gypsum mills, like sections 27, 28, 29, 31, 32, 33, and 34, Cooper township, have been prospected by core and churn drilling. Not all of the records of this work are available but many of these records will be found in chapter V. Holes drilled for wells throw considerable light on the position of the gypsum beds, and the information that it has been possible to secure in this way has been presented in chapter V also, as well as on the geological map.

Size and shape

In general it may be said that the Fort Dodge gypsum beds extend in a northeast-southwest direction; that the average width of the area is three miles and the probable length is seven miles. Des Moines river cuts through the gypsum area however, and by erosion and solution the river with its tributaries has removed the gypsum from at least three square miles of the area outlined above, and it is possible that five or six square miles must be subtracted from the gypsum area on account of the stream's activities. The amount of preglacial erosion can be determined only by actual drifting in the gypsum beds and by drilling. The older maps indicate an additional area of eight or ten square miles within which gypsum may occur. Its presence or absence here can be determined only by careful drilling and as the localities are somewhat distant from a railroad very little prospecting has so far been undertaken.

THE CENTERVILLE FIELD

The Centerville field, which will be described somewhat more fully in chapter V, is located near the southern boundary of the state, in Appanoose county. It is fortunately located with reference to gypsum-consuming markets, and in this respect enjoys advantages equal to the Fort Dodge district. While it cannot reach the Minnesota and Wisconsin markets as readily, it is nearer to Missouri, the city of St. Louis and the large cement mills about Hannibal. The mining conditions at Centerville have not proved particularly difficult. The gypsum field is near the center of Iowa's most important coal field and is within reach of hydro-electric power from the Keokuk dam. The location of this field is shown in figure 8, page 131.

Location of Centerville field

The extent of the Centerville field is not known. As the gypsum lies at a depth of 550 feet its presence must be determined wholly by drilling.

Extent of Centerville field

In the fall of 1910 the Scandinavian Coal Company located the gypsum at Centerville, while prospecting for coal near that town. Shortly thereafter two additional test holes were put down. One of these was located 1,200 feet southwest of the "Discovery hole", and went to a somewhat greater depth, 563 feet, but found no gypsum, the other, located

Discovery of Centerville gypsum

1,700 feet northwest of "Discovery hole", found 18 feet of gypsum beginning 572 feet below the surface.

Some additional drilling has been undertaken during the last two or three years but the results are not available for publication.

CHAPTER V.

STRATIGRAPHY OF THE IOWA GYPSUM AREAS

The formations that are found in the Fort Dodge gypsum area, and their geological relationships are given in the following table.

GROUP	SYSTEM	SERIES	STAGE	FORMATION
Cenozoic	Quaternary	Recent		Tufa, humus, alluvium
		Pleistocene	Wisconsin	Drift, gravel
			Kansan, Aftonian (?)	Drift, Gumbotil
Paleozoic	Permian (?)		Fort Dodge	Gypsum, red shale and sandstone
	Carboniferous	Upper Carboniferous or Pennsylvanian	Des Moines	Coal, sandstone, shale
		Lower Carboniferous or Mississippian	Ste. Genevieve	Marl and limestone
			St. Louis	Limestone, sandstone, shale

Information on which this table is based was gathered from exposures along Des Moines river; and along Soldier, Lizard, and Two Mile creeks; as well as from well records and drill holes sunk in searching for gypsum and coal.

Exposures and well data for the area will first be presented in order to set before the reader the field data in full and enable him to criticise more intelligently the deductions that are made later, when in appropriate sections, the various formations are separately considered.[111]

EXPOSURES ALONG SOLDIER CREEK

Particular interest has for many years centered about the valley of Soldier creek, a small stream that flows into the Des

[110] This chapter has been prepared by James H. Lees and Frank A. Wilder. Lees is largely responsible for the sections and the description covering the Ste. Genevieve, and has assisted in collecting and checking all data in connection with the Fort Dodge beds.

[111] On the topographic map localities are indicated by numbers which correspond to numbers in the text at the description of the locality.

Moines from the northeast in the north part of Fort Dodge. Several explanations for the peculiar relationship existing between the St. Louis limestone, the gypsum and the Coal Measures shales have been offered, the most recent being Keyes' hypothesis of faulting on a large scale.[112] An airplane view of lower Soldier creek valley is shown in figure 9.

FIG. 9.—Airplane view of part of Des Moines river valley and the lower portion of Soldier creek valley. The viaduct referred to in the text is plainly shown. Courtesy of Fort Dodge Commercial Club.

Kohl's Brewery Section. No. 1 on map

The section at the mouth of Soldier creek near the end of the ridge that separates the valley of Des Moines river from Soldier creek valley, and known as the "Kohl Brewery" section is of considerable historic interest. The old brewery long ago disappeared though portions of the foundation walls still stand to identify the spot. When studied by the writer in 1902 the section to be seen was as follows:

		Feet
9.	Gravel, fresh, clean, well water-worn, containing much limestone	5
8.	Drift, slightly oxidized, unleached	28
7.	Gravel, rusted, many decayed fragments, showing only at certain points along bluff	2
6.	Sandstone, soft, friable, buff-colored, though at points not far away it is white and heavily bedded	5
5.	Shales, argillaceous, sandy layers alternating	5
4.	Sandstone, buff, friable	2
3.	Shale, gray	2
2.	Thin bands of gypsum and shale	7
1.	Gypsum, massive (exposed)	11

112Controlling Fault Systems in Iowa: Iowa Academy of Science, Vol. XXIII, p. 103.

At present about thirty feet of red, buff and gray shales are exposed at this point, capped by a two foot bed of white sandstone. Near the base of the shale a three inch layer of gypsum appears, which probably corresponds to one of the bands referred to in No. 2 in the section above. The massive gypsum shown in No. 1 is now covered by wash from the slope.

This description agrees substantially with that of Keyes in 1893.[113] Keyes then added that "this exposure of over fifty feet of stratified rocks appears to lie in a depression in the Coal Measures, since a short distance to the north bituminous shales rise to a level considerably higher than the top of the section."

In a recent paper[114] Keyes accounts for the depression that he and others have noted by postulating a fault which depressed the gypsum series forty feet.

The sandstone bed in the Kohl Brewery section apparently is a part of an arenaceous zone that outcrops about 100 yards farther west in a cut of the Minneapolis & St. Louis Railroad and in a nearby mound isolated by the cuts of the Illinois Central Railroad and the Minneapolis & St. Louis Railroad.

At the north end of the first viaduct over Soldier creek a heavy mass of drift extends from the upland to the bridge level. Below the drift is found:

		Feet
Viaduct section. No. 2 on map	3. Red shales and shaly sandstone	15
	2. White sandstone	3
	1. Red and gray shale	35

All of the shales and sandstones of this section have been correlated by all students of the section with the Fort Dodge beds. They are exposed within five feet of the creek level.

About 100 feet above the viaduct there is an exposure of red shales and red and gray, heavy bedded sandstone which rises thirty feet or more above the water. The sandstone is not of uniform hardness, some parts being quite soft. Crystals of celestite (strontium sulphate) in nodular masses, some of them a foot in diameter, occur in the shales. This section is illustrated in figure 10.

113Gypsum Deposits of Iowa: Iowa Geol. Survey, Vol. III, p. 273, 1893.

114Iowa Academy of Science, Vol. XXIII, p. 109.

Just below the plant of the Fort Dodge Culvert and Iron Works, in the bluff which forms the north bank of the creek, the following section appears:

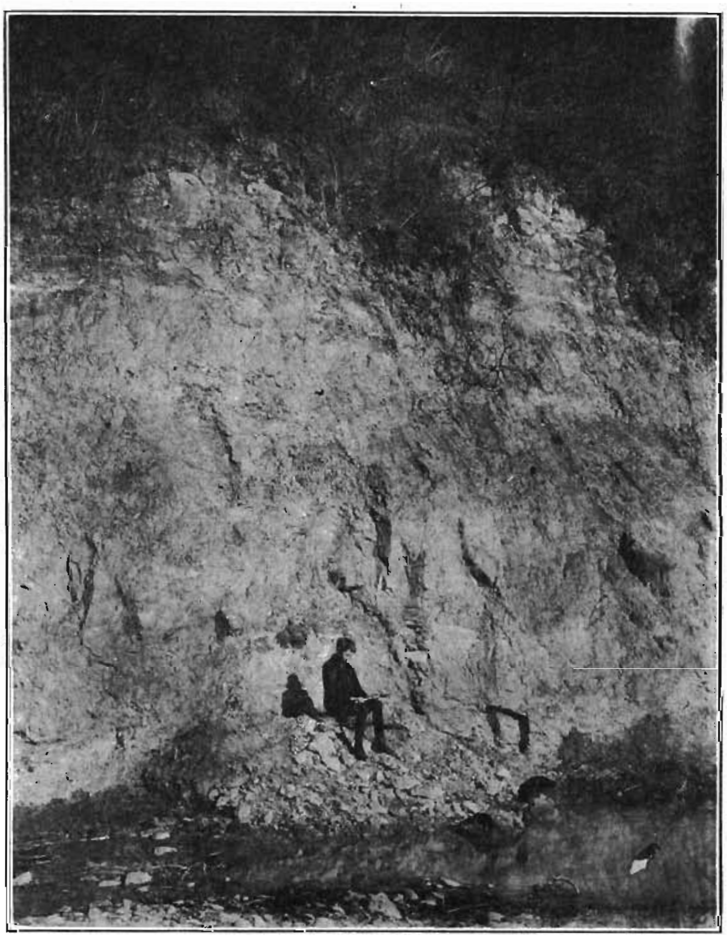


FIG. 10.—Shales and sandstones near lower viaduct over Soldier creek. Photo by Lees.

			Feet	Inches
Iron Works section. No. 3 on map	8.	Drift		
	7.	Green marl	10	
	6.	Crystalline limestone		3
	5.	Lithographic limestone	1	
	4.	Gray marl	1	
	3.	Sandstone, gray, soft streaks	7	
	2.	Gray sand		10
	1.	Brown limestone	3	

This section with the exception of No. 8 (drift) and the possible exception of No. 7 (green marl) is correlated with the St. Louis, which exhibits similar characteristics at typical exposures elsewhere in the county.

About 100 yards farther up stream occurs a similar section which is repeated a short distance beyond, at the stone bridge.[115]

			Feet	Inches
Stone bridge section. No. 4 on map	6.	Drift and gravel		
	5.	Shale, black, thinly laminated	10	
	4.	Lithographic limestone	2	
	3.	White sandstone	6	
	2.	Lithographic limestone		6
	1.	Brown limestone	6	

Aside from the drift and the shale all the members of this section are to be regarded as belonging to the St. Louis.

About 150 feet north of the stone bridge red and blue-green clay shales appear in a small gully and red clay shales appear at creek level only fifty feet farther on. About 600 feet farther on, where the creek approaches the railroad, black clay shales are exposed at stream level.

The pit of the Hawkeye Clay Works, about one-fourth mile above the stone bridge, in section 19, Cooper township, shows:

			Feet
Hawkeye Clay Works. No. 5 on map	7.	Drift	
	6.	Gypsum (scattered blocks)	3
	5.	Shale, black in lower half, upper half red, gray, etc.	40
	4.	Shale, black and gray, sandy	6
	3.	Shale, black	2
	2.	Sandstone, fine, gray and yellow	4
	1.	Shale, black, laminated, to creek	20

Aside from the drift and the gypsum the members of this section plainly belong to the Coal Measures.

Old lime kiln

At the upper end of the brick yard is an old lime kiln. Across the creek and 100 feet to the north limestone is exposed in a low dome rising three feet above the water, and this body of rock doubtless furnished the material that was used in the old kiln. Above the limestone occur red and green shales similar to those above the stone bridge farther down the stream. In both cases the bright shales may be referred to the Des Moines beds. Only 100 yards farther up

115Most of the sections given in this chapter are taken from field notes made by Lees after a visit to all the localities with Wilder. Subsequently Lees visited the localities again and confirmed the earlier observations and correlations. The Soldier creek sections were checked three times by Lees and Wilder during as many consecutive summers.

stream the limestone disappears and its place is taken by black shales.

Gypsum near railroad bridge. No. 6 on map

Just above the first steel railroad bridge, which is about one-fourth of a mile beyond the brick yard, gypsum appears near water level, and 180 yards farther up it rises from water level twelve feet and is covered with thirty feet of dark red shales in which are streaks of bluish sandstone. This outcrop is shown in figure 11.

FIG. 11.—Gypsum on Soldier creek. Photo by Lees.

Gypsum at second steel bridge. No. 7 on map

At the second steel railroad bridge, opposite the south end of the cemetery the gypsum extends below water level and rises eighteen feet above the surface of the water. As in other exposures, it is overlain by red and blue sandy shales.

A little farther upstream and just beyond the viaduct leading to the cemetery, black shales appear along the creek for several hundred yards, while near the third railroad bridge close to the line between sections 9 and 16, Cooper township, the shales are much lighter in color.

The last known important exposure of the shales and sandstones of the Fort Dodge beds is at the Haviland pit, now abandoned, 125 yards above the third steel railroad bridge. Here at least twenty feet of red sandy shales is to be seen, with a four foot ledge of gray rather hard sandstone about the middle of the pit. Evidently these red sandy shales rest on a very irregular surface of black and red fissile clay shales of the Des Moines stage, for these are exposed in a nearby ditch at a level just below the floor of the pit, and at several nearby points along the creek sandy and clayey shales alternate at similar levels.

The Haviland pit. No. 8 on map

In his report on Webster county the writer stated that the repeated changes of the strata at water level of Soldier creek, from limestone and its associated sandy beds; to gypsum with its associated sandy shales; and from either of these to black clay shales of the Coal Measures, can be accounted for only by a pronounced unconformity between the St. Louis limestone series and the overlying Coal Measures (the Des Moines stage of the Pennsylvanian) and an unconformity between the gypsum series (Fort Dodge beds) and the beds that underlie it. At some points on Soldier creek these underlying beds belong to the St. Louis stage and at others to the Des Moines. The St. Louis limestone projects well up through the black shales at numerous points. The gypsum and shales of the Fort Dodge beds were deposited in a rather broad valley which was cut through the Coal Measures shales at numerous points while at others there was left only a relatively thin body of the black shales to separate the gypsum from the St. Louis limestone.

EXPOSURES ALONG DES MOINES RIVER NORTH OF SOLDIER CREEK

The clay pit of the Fort Dodge Brick & Tile Works deserves very careful consideration in connection with the study of all the formations that occur within the gypsum area. In view of the fact that sections from this pit are given by various writers, and because there have been various stages of development and abandon-

Pit of Fort Dodge Brick and Tile Works. No. 9 on map ment in the pit itself conditions will be described with considerable detail.

As early as 1902, what may be called the main southern part of the pit had been developed and abandoned, and the main effort toward winning clay had extended toward the north. At that time, however, on the extreme southern end of the pit, well down the river valley slope, some work was being done and the pit then showed the section given by Wilder.[116] This part of the pit had been abandoned, with the exception noted, probably on account of the excess of sand in the shales in the upper part of the face of the pit. Keyes and Wilder both gave sections of the north end of the pit where, in spite of the fact that the pit has receded many feet in a northerly direction, the section has not changed in any material way since 1902. Wilder's section was published in connection with a discussion of the Pleistocene of Iowa and did not differentiate the shales underlying the till, classing them all as Coal Measures.

Keyes analyzed the shales somewhat more carefully[117] and his section is given below.

		Feet
9.	Till, ashen, with pebble bands	15
8.	Shale, blue, yellow and variegated	18
7.	Sandstone, gray, massive	2
6.	Shale, black and gray with coal seams	11
5.	Shale, white (fireclay)	2
4.	Shale, light colored and variegated	15
3.	Shale, dark colored, partly hidden at base	25
2.	Sandstone, coarse, conglomerate, ferruginous	1
1.	Limestone, gray	30

This same section as seen and carefully measured by Lees and Wilder in 1917 showed:

		Feet
7.	Drift, yellow	4
6.	Drift, gray or ashen	23
5.	Shale, pink, gray, purple, yellow, mottled	12
4.	Sandstone, gray, massive	12
3.	Shale, black	12
2.	Shale, gray, its surface sloping and sharply defined from the black shale above	12
1.	Shale, green, smooth, soapy feel	2

In the floor of the pit green-gray marls are exposed. This floor is twelve or fifteen feet above the river, which is located a hundred feet to the west. At the water's edge a foot or two

[116]Iowa Geol. Survey, Vol. XII, p. 129, 2d section.
[117]Iowa Acad. Science, Vol. XXIII, p. 109, 1916.

of limestone are exposed, and Keyes' section of the clay pit is to be taken as a composite for he shows thirty feet of limestone in the clay pit section.

Lees, in 1918, by digging, exposed a portion of the covered south end of the old pit, and exposed red and gray sandy shale which he correlated with similar shales of the Fort Dodge beds. A pit foreman reported finding a gypsum block above the clay shales in 1917 and Lees and Wilder found about a ton of gypsum at the base of the pit in the summer of 1921 with material that had slid down from higher levels. Later in the same year Lees observed several small fragments of gypsum and red and pink sandy shale which had come down into the pit with the slump.

The two feet assigned by Keyes as the thickness of the gray massive sandstone is evidently an error in field notes, for the thickness is twelve feet. His white shale or fire clay (No. 5) could not be identified in 1917.

There are at least six exposures of the sandy shales of the Fort Dodge beds between the old Kohl Brewery exposure and the pit of the Fort Dodge Brick and Tile plant. The demonstrated continuity of these beds is important, since the hypothesis has been advanced that due to faulting the Fort Dodge beds have been cut out in this locality. Instead of a fault there seems to be evidence of an erosion basin which rises to the north from Kohl's Brewery to the tile pit, about forty feet in fifteen hundred feet of horizontal distance.

Along the river two hundred yards north of the pit the sandstone ledge outcrops at about the same level as at the pit and below it are twenty feet of dark shale. Under the shale is a ledge of yellow sandstone about seven feet thick. Limestone spalls may be seen at the water's edge and upstream a hundred yards farther a limestone ledge rises a foot above low water level.

Excavations at the east end of the dam not far from here gave the following section:

			Feet
No. 10 on map	5.	Drift	
	4.	Green shale with selenite crystals	3
	3.	Sandy shale	4
	2.	Sandstone, light gray	5
	1.	Limestone, above water level	8

The excavation at the west side of the dam was seen by Lees at a time when it was considerably below water level. He reports:

			FEET
No. 11 on map	4.	Limestone	?
		water level	
	3.	Limestone	8
	2.	Green shale	3
	1.	Fine-grained green sandstone	6

Continuing up the east bank of the river, alternating exposures of dark shales, sandstones of the Coal Measures, and limestones are found at water level to the northern border of the county.

In 1918 Lees[118] located an interesting exposure on the west side of the river near the dam. This was found in a ravine which opens into the Des Moines valley from the northwest. Just above its mouth this ravine shows:

			FEET	INCHES
No. 12 on map	6.	Coal Measures shales	20	
	5.	Red clay shale	10	
	4.	Light gray shale, richly fossiliferous	7	
	3.	Hard yellow to gray shale	1	6
	2.	Green-gray clay	1	6
	1.	Dark red clay	3	

The shale members of this section with the exception of No. 6 have on fresh exposure a striking starchy texture which breaks down to marly texture on exposure. In this they resemble the shales exposed on Lizard creek in a section which occurs almost a mile due west. The fossils in the shales of zone 4 are the same as those determined for the Lizard creek section and set out on page 146.

LIZARD CREEK SECTIONS

Lizard creek, flowing from the west, empties into the Des Moines half a mile above the mouth of Soldier creek, which joins the parent stream from the east. Good natural exposures occur along its banks and greatly aid in determining stratigraphic problems in the northeastern portion of the gypsum area.

Limestones show along both banks of the stream and underlie the flat between the Illinois Central railroad and the creek. On the left bank of the creek ten or twelve feet of gray sand-

118Iowa Acad. Science, Vol. XXV, p. 599, 1918.

stone appears above the limestone. About 500 yards above the mouth of the creek on this side is one of the old clay pits of the Fort Dodge Clay Works. This plant is at present dismantled. It is located on the right bank of Des Moines river just below the mouth of Lizard creek. Clay was secured from two pits; first in the bank of the river back of the kilns, and later six hundred yards away on the left bank of Lizard creek. The location of these pits, and of other localities described above is shown on the topographic map, numbers 13 and 14.

Fort Dodge Clay Works

The clay pit on the left bank of Lizard creek furnished the material for the Fort Dodge Clay Works twenty years ago. The section as now seen is somewhat obscure at certain points due to slides, but the following is approximately correct.

North pit. No. 13 on map

		Feet
8.	Drift	30
7.	Gypsum	6
6.	Shale, very dark, fissile	7
5.	Shale, nature obscure on account of slumping	10
4.	Shale, red, green and gray, some bands having a pronounced starchy texture	20
3.	Gray marl, with fossils	20
2.	Sandstone	2
1.	Limestone, to water level	10

Fossils from zone 4 of the section given above, collected by Lees and identified by Thomas are listed below:

Spirifer pellaensis (Weller)
Pugnoides ottumwa (White)
Girtyella indianensis Girty
Composita trinuclea (Hall)
Orthotetes kaskaskiensis (McChesney)
Clionolithes n. sp.
Spirorbis n. sp.
Crania (unidentified)
Liopora?
Trilobite, imperfect pygidium

Professor Thomas comments on this collection as follows:

"The Orthotetes is larger, judging from the fragments, than any described under the name I have suggested but otherwise tallies in every way. The two first named species are the most abundant and they are the index fossils of the Ste. Genevieve. Girtyella is common in this formation elsewhere, but we got only one specimen."

A short distance farther up Lizard creek, on the right bank in the center of section 24, Douglas township, the following composite section was developed from water level of the creek up through the cut on the Illinois Central railroad, and published on the report on Webster county.[119] The fossils were identified by Professor Calvin.

		Feet
5.	Coal Measures covered by slope wash	30
4.	Fossil-bearing marl, *Spirifer littoni* Swallow, *Pugnax ottumwa* White, *Seminula subquadrata* Hall, *Dentalium* sp., abundant	6
3.	Marl, gray, without fossils, containing many small selenite crystals	40
2.	Sandstone, yellow, moderately hard, showing little lamination, calcareous	2
1.	Limestone, slightly folded, in definite layers, average thickness of largest eight inches, in places brecciated, though not showing a layer that is brecciated throughout, as in exposures in Des Moines river north of Fort Dodge	17

Other exposures up Lizard creek will be presented in the description of the Ste. Genevieve formation.

DES MOINES RIVER SECTIONS BELOW LIZARD CREEK

South pit.
No. 14 on map

The main clay pit of the Fort Dodge Clay Works was actively operated when the report on Webster county was published and an excellent opportunity to study conditions at this important point then existed. The section recorded is given below:

Section in the Pit of the Fort Dodge Clay Works:

		Feet
3.	Drift, yellow, unleached, lower part a little darker than the upper	35
2.	Red sandy shale with occasional thin bands of sandstone	10
1.	Gray Coal Measures shales, containing numerous fossils of ferns and lepidodendrons. A few iron nodules and crystals of selenite present. Separated from red shales above by sharp line of unconformity. Along the line of separation there is a layer of gumbo, one foot thick	30

The following statement was made:

"No. 2 includes the red shales found in so many places above the gypsum. These red sandy shales are so characteristic and are associated so conformably with the gypsum that they may safely be regarded as of the same age as the gypsum. The occurrence of the light colored, calcareous sandstone free from fossils with these red shales is also significant."

[119] Iowa Geol. Survey, Vol. XII, pp. 78-79.

It is worth noting here that the relations between the Coal Measures and the Fort Dodge beds are the same on this side of the Des Moines valley as they are in the east bluff, namely that the contact surface rises to the north. In the south pit the Fort Dodge beds come down within about forty-five feet of the river; in the north pit, across Lizard creek, the gypsum lies seventy feet above the water.

Between Lizard creek and the viaduct crossing to West Fort Dodge, there are few exposures. On the west bank of the river, at the foot of the bluff below the Country Club there are abandoned drift mines from which coal was taken not many years ago. These pits are directly opposite the city of Fort Dodge and a little below the mouth of Soldier creek. They are about fifteen feet above water level. Just above them lies an eighteen inch fossiliferous limestone ledge, which appears in a number of places within the next two miles down the river.

Bradshaw Clay pit. No. 15 on map

The first gypsum showing down the river below Soldier creek is found at the Bradshaw Clay plant, in the northeast quarter of section 32, Cooper township, on the east bank of the river and in the edge of the city of Fort Dodge. The section here is as follows:

		Feet	Inches
9.	Drift	5	
8.	Red sandy clay	12	
7.	Blocks of gypsum, in a yellow clay (unconformity, sharp contact)	4	
6.	Black shale	20	
5.	Dark gray limestone, fossiliferous	1	6
4.	Black coaly shale		10
3.	Black shale	3	
2.	Fire clay	1	
1.	Dark gray shale	20	

The surface of the black shale, No. 6 in section above, forms a sharp contact with the red clays and gypsum just above it.

About one hundred yards above the Bradshaw pit, in the east bank of the river there is an exposure of ten to twelve feet of black and dark red clay shale that dips strongly to the north. About one-third of the distance from the Bradshaw pit to the Chicago Great Western viaduct sandstones are exposed in a little ravine, and these beds dip strongly to the south.

On the west side of the river about two hundred yards south of the Chicago Great Western viaduct is an abandoned brick yard which shows the following section:

		Feet
3.	Drift	
2.	Dark red and gray clay shales with red sandstone, blocks of reddish limestone with brachiopods, orthoceras and corals	5
1.	Black shales	20

The Plymouth Gypsum Company's mine on the west bank of the river, in southwest quarter of section 31, Cooper township, shows a yellow sandstone overlying the gypsum. At the old clay pit near the mouth of the ravine in which the Plymouth mine is located, at a level about five feet below the level of the gypsum three hundred yards farther up the ravine, occurs an eighteen inch ledge of dark gray fossiliferous limestone. The fossil content of this ledge is the same as that of the similar ledge in the Bradshaw pit across the river and of the old clay pit described above as located on the west side of the river near the the Chicago Great Western viaduct.

Plymouth Gypsum Company's mine. No. 16 on map

About two miles farther down stream the Fort Dodge, Des Moines and Southern electric railroad crosses the river and ascends to the upland on the west side through a ravine which gives interesting exposures. At the mouth of the ravine the railroad cuts through a spur in the bluff and, following up from water level so as to include this cut, the following section is developed:

Interurban exposures. No. 17 on map

		Feet
6.	Sod	
5.	Gypsum	1
4.	Red and varicolored shales with sandy layers	30
3.	Black shale rising nearly to track level	20
2.	Black limestone band	1
1.	Black shale	30

For some distance up the ravine the red shales show a thickness of twelve to thirty feet. Above the red shale and six inches below the gypsum, which may be seen overlying it at various points, there appears a red or gray fossil-bearing conglomerate one foot to two feet thick. The pebbles are for the most part limestone. This conglomerate is shown in figure 13, page 169.

A generalized section of this ravine may be described as follows:

		Feet	Inches
8.	Drift	0-30	
7.	Gypsum	10-15	
6.	Clay		6
5.	Conglomerate	1-2	
4.	Red clay	12-30	
3.	Gray sandstone	6	
2.	Gray sand	2	
1.	Black shale	30	

The gray sandstone (No. 3) and the conglomerate are not constant, and it will be noted that they do not show in the section given for the mouth of the ravine. On the other hand

FIG. 12.—Gypsum at the Vincent Clay pit, exposed by hydraulic stripping, described somewhat fully in the text. Photo by Lees.

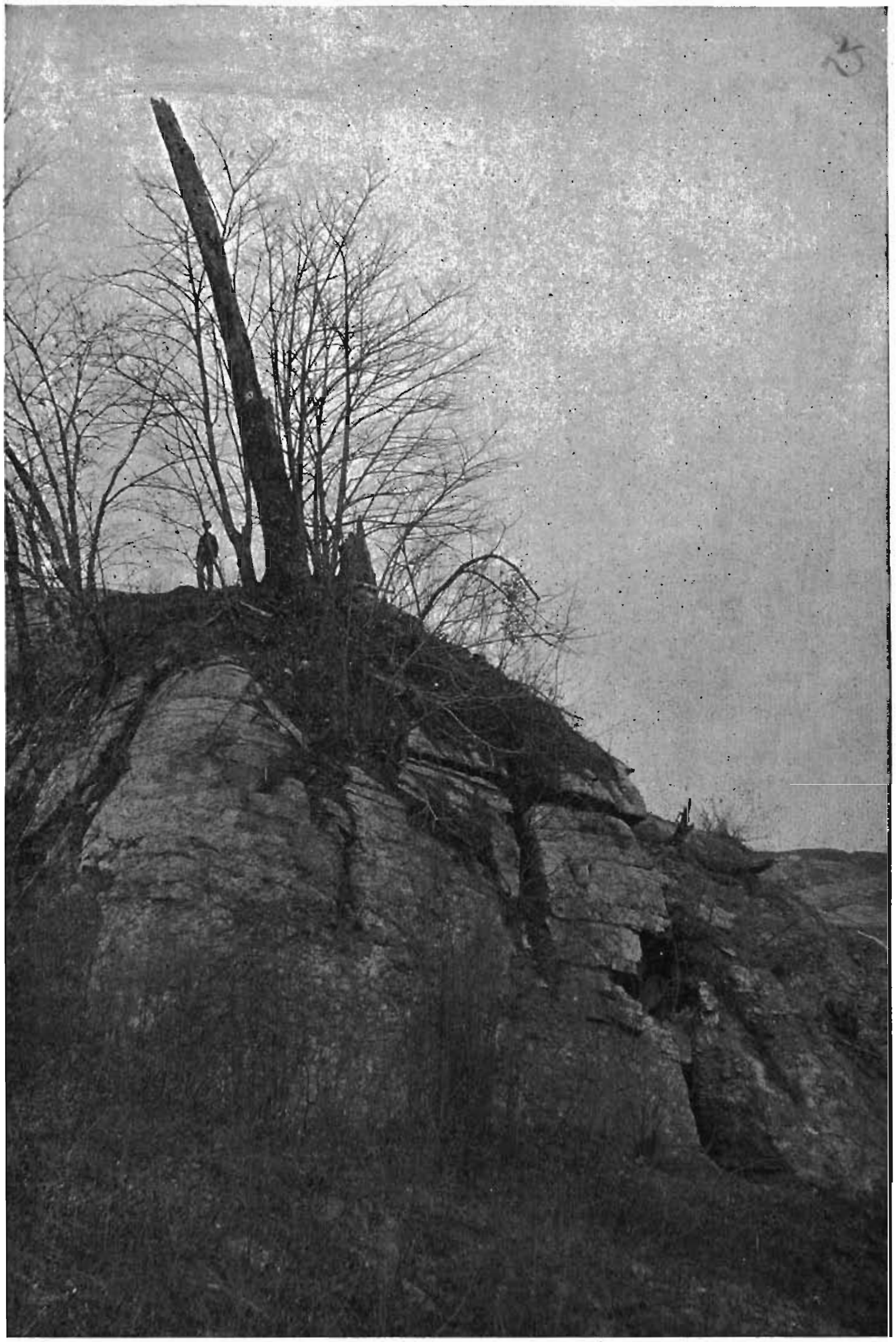
they appear again across the river in the Vincent clay pit as shown below.

Vincent Clay pit. No. 18 on map

The plant of the Vincent Clay Products Company is located near the center of section 6, Pleasant Valley township, and the pit gives the following section:

VINCENT CLAY PIT SECTION

		Feet
9.	Drift	0- 8
8.	Gypsum	0- 6
7.	Red and gray conglomerate	0- 1½
6.	Varicolored clays darker toward base	15-20
5.	Gray sandstone, hard in places, elsewhere soft	10-15



Gypsum outcrop near Des Moines river. Jointing and bedding are both shown.

4.	Varicolored sandy shales, not so bright as No. 6, above	6
3.	Black finely fissile shales, rather sharply set off at contact from 4	15
2.	Limestone	1½
1.	Black shale, exposed	6

The gypsum at this pit is shown in figure 12, which shows well its extremely irregular surface.

Gypsum Hollow exposures. No. 19 on map

At the mouth of Two Mile creek, better known as Gypsum Hollow, immediately south of the Vincent pit, twenty-five feet of red shales with one foot of gypsum above are exposed on the west wall of the valley. A few yards farther up one foot of conglomerate appears under the gypsum, and five feet of black laminated clay shows under the red clays. The red clays are black toward their base but are not as well laminated as typical Coal Measures clays. One hundred yards up the ravine the gray sandstone (No. 5 in the Vincent clay pit section) appears. It is six feet thick, dips a little to the north, and is overlain by red clays above which in places some gypsum occurs.

For nearly a mile up Gypsum Hollow, gypsum is exposed at intervals and there are numerous old quarries from which material to operate two mills, long since dismantled, was secured during the nineties. Plate V shows an outcrop of gypsum in this vicinity. The last exposure to be seen in going up the valley is an old opening which shows three to four feet of dark red sandy shale and soft sandstone. Below these beds is the gypsum, several feet of which is shown. The upper surface of the rock, which is laid bare over an area several rods in extent, is marked by solution channels and low domes two to three feet in diameter and a foot or less in height. These are shown in figure 27 on page 205.

Gilmore Portland Cement Company's pit. No. 20 on map

About two hundred yards down the east wall of Des Moines valley from the mouth of Gypsum Hollow is the pit from which the Gilmore Portland Cement Company gets the shale for its plant at Gilmore City. The section is as follows:

		Feet
5.	Gypsum	6
4.	Bright clay shale	6
3.	Dark clay shale	6
2.	Limestone	0-2
1.	Gray shale	7

The limestone, No. 2, is two feet thick on the sides of the pit nearest the river, but disappears entirely twenty-five feet farther east.

In the river about one-half mile east of this point along the east bank, one-fourth mile below the Minneapolis and St. Louis railroad bridge in Pleasant Valley township, the southwest quarter of section 5, the marls of the Ste. Genevieve may be seen rising a few feet above water level. They are characterized by the same fossils that are found in these beds on Lizard creek and listed on page 146. Below the marl a few feet of limestone appears. The entire exposed area of limestone and marl does not include more than ten acres.

River exposure. No. 21 on map

Continuing down the river from Gypsum Hollow on the west bank to the southwest quarter of section 5, Pleasant Valley township, the clay pit of Johnson Brothers gives the next series of exposures. The section is as follows:

Johnson Brothers clay pit. No. 22 on map

		Feet
4.	Gravel	4-10
3.	Clay, dark gray, noncalcareous	½- 1½
2.	Gypsum	0- 4
1.	Shale, black above, red and gray below, sandy	20

The bed of the pit is a limy shale which contains some pyrite nodules.

An old pit just south of the one in present use was opened in light colored red, gray, and purple sandy shales with concretions and fossils of Stigmaria, Lepidodendron, etc. These shales differ from those over the gypsum and doubtless belong to the Coal Measures series.

About one-fourth mile farther down the river is the pit of Plymouth Clay Products Company. No gypsum is found here but twenty-five feet of red and gray shale like that in the old (south) Johnson pit, is exposed. It shows a strong dip to the west.

Pit of Plymouth Clay Products Company. No. 23 on map

The light colored sandy shales can be traced with ease to the ravine which joins the river valley one-fourth of a mile farther south (in north of southwest quarter of section 8, township 88 north, range 28 west). On the north side of this ravine, which is about thirty-five feet deep, the light colored shales are very conspicuous, while on the south side, two hundred feet away, they are replaced at least in part by dark Coal Measures shales. A few feet of light gray shale overlies the dark shale. At the level of an abandoned clay pit on the north side, which shows the bright shales, there is an abandoned drift which evidently was a prospect for coal. About two hundred yards up this ravine the dark Coal Measures shales are exposed under a few feet of the light colored shales and a heavy sandstone ledge appears up the ravine. This seems to be a part of the sandstone ledge that has been described as occurring at various points farther up the river.

Ravine exposure. No. 24 on map

The sandstone just referred to outcrops in the sides of the ravine known as Craig's Hollow, two-thirds of a mile farther south and about an equal distance north of Kalo, in the northern part of section 18. No gypsum is seen in Craig's Hollow nor are any of the bright shales found here. About twenty feet below the sandstone, and in the bed of the creek at places, a black limestone ledge appears, which coincides with a similar ledge already described from numerous points farther to the north.

Craig's Hollow

From Craig's Hollow to Kalo and thence to the south only Coal Measures shales are found, with the exception of certain exposures of St. Louis limestone in the bed of the river below Kalo and the mouth of Holiday creek.

Holiday creek is the largest tributary of the Des Moines in the southern part of the gypsum area. Flowing nearly south it crosses two sections in Cooper township and two in Pleasant Valley township, and in section 10 of the last named township it has cut into the indurated rocks, but there are no exposures of gypsum or associated beds. In this section nothing but Coal Measures shales appear. If the Holiday creek depressions were deep enough to reach the formations beneath the drift in section 3 just to the north, there is every reason to believe that the gypsum series would be exposed, since gypsum has been found in shafts and wells as will be set out later.

Holiday creek

A small ravine on the left bank of the river, in the southeast quarter of section 5, Pleasant Valley township, is cut through gypsum for half a mile. About eight feet of gypsum is exposed. The heavy bed of gray sandstone, so consistently reported in exposures on both sides of the river from the Vincent pit south, appears in the ravine, and in places is in contact with the gypsum, while at other points it is separated from the gypsum by ten to fifteen feet of shale.

Gypsum in ravine. No. 25 on map

The black limestone found in the Vincent clay pit (No. 2 of section) about thirty feet above water level rises to the east and in the northern part of section 5, Pleasant Valley township, it is sixty or seventy feet above the river.

DATA FROM DRILL RECORDS

The structural information given by exposures described above is supplemented by information obtained in shaft sinking, and in prospect and well drilling. Keyes in his paper in 1894 reported wells as follows:

Well on Webster County Poor Farm. No. 26 on map

"Southwest of Fort Dodge and from one and one-half to two miles from the river, several drill holes have been put down in the vicinity of the county poor farm. The well on the poor farm (Tp. 88 N., R. XXIX W., Sec. 3, SW. qr., NE. ¼), passed through seventeen feet of gypsum at a depth of eighty-three feet. The record is as follows:

		Feet	Inches
23.	Soil	2	
22.	Clay, yellow	13	
21.	Clay, blue	47	
20.	Sand	1	6
19.	Clay, "hard pan"	19	4
18.	Gypsum	17	
17.	Shale, blue, "soapstone"	6	2

In July, 1922, Thorpe Bros., well drillers of Des Moines, submitted to Dr. Lees the log of a well recently drilled by them on the Webster County farm. This record is given verbatim below. The absence of gypsum at about eighty feet, and its presence at three hundred sixty to three hundred eighty-seven, is remarkable, so remarkable indeed as to cast doubt on the accuracy of the record.

Thickness		Depth
2 ft.	Soil	2 ft.
20 ft.	Yellow Clay	22 ft.
63 ft.	Blue Clay	85 ft.
35 ft.	Yellow Clay	120 ft.
46 ft.	Red Clay	166 ft.
2 ft.	Lime rock	168 ft.
7 ft.	Shale	175 ft.
10 ft.	Lime rock	185 ft.
18 ft.	Shale	203 ft.
36 ft.	Lime rock	239 ft.
36 ft.	Lime and streaks of shale	275 ft.
41 ft.	Hard lime rock	316 ft.
24 ft.	Green shale	340 ft.
20 ft.	Hard lime rock	360 ft.
27 ft.	Gip rock	387 ft.
118 ft.	Solid lime	505 ft.

		Feet	Inches
16.	Limerock, black	2	
15.	Coal		9
14.	Fire clay	1	6
13.	Shale, light colored	1	4
12.	Coal	1	3
11.	Sandstone	4	
10.	Shale, black	4	2
9.	Coal		3
8.	Fire clay	1	
7.	Sandstone, white	4	6
6.	Shale, with limestone bands	34	6
5.	Shale, light colored	5	
4.	Shale, blue	4	
3.	Limestone, or hard calcareous shales	6	5
2.	Shale, blue	21	2
1.	Limestone (penetrated)	40	

One mile to the north, the Craig Coal Company has prospected at the head of what is known as Elkhorn ravine (Tp. 89 N., R. XXIX W., Sec. 36, SE. qr., NW. ¼). Sixteen feet of gypsum was found at a depth of seventy-six feet. A third layer one foot thick exists just above the main mass and is separated from it by seven inches of clay or shale.

Cooper township, Section 33. No. 27 on map

"Southeast of Fort Dodge, a couple of miles, a number of borings have been made to the east of the head of 'gypsum hollow', showing from fifteen to twenty feet of gypsum at a depth of about fifty feet. One of the holes made in township 89 north, range 28 west, section thirty-three (SE. qr., SW. ¼) showed the following succession of strata:

		Feet	Inches
22.	Soil	6	
21.	Clay, yellow and blue	14	
20.	Shale, red and yellow	6	
19.	Gypsum	16	10
18.	Shale	1	6
17.	Sandstone, white	2	
16.	Sandstone, brown	1	
15.	Shale, reddish	2	
14.	Shale, yellow	2	4
13.	Shale, dark colored	14	6
12.	Fire clay	3	1
11.	Shale, black	3	
10.	Coal	1	10
9.	Sandstone	3	
8.	Shale, light colored	2	2
7.	Shale, black		3
6.	Sandstone	1	
5.	Shale, black	4	
4.	Fire clay	1	6
3.	Shale, black	3	
2.	Sandstone, soft		4
1.	Limerock, black (penetrated)		3

There were other holes drilled on the same quarter section, each giving practically the same sequence of strata.

"Two and one-half miles to the southeast, on the Holiday farm and near by (Tp. 88 N., R. XXVIII W., Sec. 4, SE. qr.), four holes have been put down. Gypsum was struck at depths varying from 50 to 125 feet, the variation in depths being due largely to the differences in altitudes of the surface. In the two holes farthest north the gypsum was nine to twelve feet thick. Hole number 3 was near the center of the quarter section indicated:

Pleasant Valley township, Section 4 No. 28 on map

		Feet	Inches
11.	Soil	2	
10.	Clay, yellow	17	
9.	Clay, blue	25	6
8.	Shale, red	2	6
7.	Gypsum	12	
6.	Shale, black	5	6
5.	Coal	2	
4.	Fire clay	4	6
3.	Shale, gray	5	6
2.	Sandstone	16	
1.	Shale, black	1	

Northwest of Kalo, for a distance of one mile, numerous prospect holes have been put down by various coal companies. Near the center of section 7, township 88 north, range 28 west, the gypsum is fifty-eight feet from the surface, and only one foot thick. South of this point no gypsum has been reported, though a large number of drill holes have been put down much below this level.

Five miles northeast of Fort Dodge on the Groebner farm (Tp. 89 N., R. XXVIII W., Sec. 12), a well eighty feet in depth gave this section:

		Feet
4.	Soil	2
3.	Clay, yellow above, blue below	50
2.	Shale, red, sandy	26
1.	Gypsum (penetrated)	4

In the Flattery well, which is about one mile east of the Groebner place (Tp. 89 N., R. XXVII W., Sec. 7, SE. qr., SW. ¼), the same bed was encountered at a depth of forty feet, and fifteen feet of gypsum penetrated."

Wilder in 1902[120] obtained the following additional well and drill data:

[120]Iowa Geol. Survey, Vol. XII, pp. 105-108, (Webster County).

WELL DATA FOR CENTRAL AND NORTHERN WEBSTER COUNTY

TOWNSHIP	SECTION	AUTHORITY	DEPTH IN FT.	STRATA PASSED THROUGH. THICKNESS IN FEET.
Newark	Sec. 27, Sw. ¼	Schmaker	126	Drift and blue clay, below which was gypsum.
Newark	Creamery at Vincent	Schmaker	80	Drift, 66; gypsum, 14.
Newark	Sec. 32, Nw. ¼	J. J. Meyer	118	Wholly in drift.
Badger	Sec. 25, Nw. ¼	J. J. Meyer	130	Drift, 70; sandstone, 4; clay, 25; sandstone, 30.
Badger	Sec. 31, Sw. ¼	J. J. Meyer	96	Drift, 80; sandstone, 16.
Badger	Sec. 31, Nw. ¼	J. J. Meyer	110	Wholly in drift.
Badger	Sec. 34, Sw. ¼	J. J. Meyer	......	Depth not known, entered sandstone under drift.
Badger	Sec. 29, Nw. ¼	J. J. Meyer	70	Drift, 68; sandstone, 2.
Badger	Sec. 22, Sw. ¼	J. J. Meyer	120	Drift, 100; sandstone, 20.
Badger	Sec. 34, Sw. ¼	J. J. Meyer	125	Drift, 55; sandstone, 8; soft sandstone, 40; clay, 2, sandstone, 20.
Badger	Sec. 11, Sw. ¼	J. J. Meyer	120	Drift, 90; sandstone, 30.
Badger	Sec. 14, W. ½	J. J. Meyer	140	Drift, 90; sandstone, 50.
Badger	Sec. 17, Sw. ¼	J. J. Meyer	100+	Drift, 100; ent'd sandstone.
Badger	Sec. 22, Nw. ¼	J. J. Meyer	144	Drift, 80; sandstone, 4; red clay, 60.
Badger	Sec. 20, Nw. ¼	J. J. Meyer	118	Drift, 100; hard sandst'e, 18.
Badger	Sec. 16, Sw. ¼	Lappint	108	Wholly in drift.
Badger	Sec. 33, Nw. ¼	Lappint	70	Drift, 50; limestone, 20.
Badger	Sec. 33, Nw. ¼	Lappint	120	Wholly in drift.
Badger	Sec. 20, Sw. ¼	Lappint	113	Drift, 50; sandstone, 6; clay, 50; sandstone, 7.
Badger	Sec. 20, Sw. ¼	Lappint	116	Drift, 60; sandstone, 6; clay, 20; limestone, 30.
Badger	Sec. 32, Se. ¼	Lappint	120	Drift, 80; red clay, 40; sandstone.
Badger	Sec. 33, Sw. ¼	Lappint	90+	Drift, 90; stopped in sandst.
Badger	Sec. 34, Sw. ¼	Lappint	68	Drift, 50; sandstone, 1; limestone, 17.
Colfax	Sec. 18, Sw. ¼	Lappint	50	Drift, 49; enter gypsum 5 in.
Colfax	Sec. 17, S. ½	Lappint	158	Drift, 90; shale, 61; limest'e.
Colfax	Sec. 8, Sw. ¼	Lappint	83	Drift, 60; gypsum, 23.
Colfax	Sec. 9, Nw. ¼	J. J. Meyer	132	Drift, 125; sandstone, 7.
Colfax	Sec. 7, Nw. ¼	J. J. Meyer	106	Wholly in drift.
Cooper	Sec. 4, Ne. ¼	Lappint	67	Drift, 40; red clay, 20; limestone, 7.
Cooper	Sec. 9, Nw. ¼	Lappint	90	Drift, 85; limestone, 5.
Cooper	Sec. 12, W. ½	Lappint	75	Drift, 60; sandst'e, 4; gyps.
Cooper	Sec. 33, Ne. ¼	Craig Coal Co.	42	Drift, 26; gypsum, 16.
Cooper	Sec. 23, Sw. ¼	Lappint	125	Drift, 120; limestone, 5.
Cooper	Sec. 23, Sw. ¼	Lappint	81	Drift, 70; sandstone, 2; gypsum, 9.
Cooper	Sec. 26, S. ½	Lappint	101	Drift, 100; limestone, 1.
Cooper	Sec. 26, Nw. ¼	Lappint	80	Drift, 60; gypsum, 20.
Cooper	Sec. 34, Sw. ¼	Lappint	72	Drift, 47; gypsum, 25.
Cooper	Sec. 28, Se. ¼	J. J. Meyer	78	Drift, 57; gypsum, 21.
Cooper	Sec. 8, Nw. ¼	J. J. Meyer	70+	Drift, 70; sandstone.
Cooper	Sec. 16,	J. J. Meyer	87	Drift, 75; sandstone, 4; clay, 4; sandstone, 4.
Cooper	Sec. 10, Nw. ¼	J. J. Meyer	100	Drift, 80; sandstone, 20.
Douglas	Sec. 36, Se. ¼	Craig Coal Co.	109	Drift, 76; gypsum, 18.
Douglas	Sec. 11, Se. ¼	J. J. Meyer	150	Drift, 136; sand, 14.
Washington	Sec. 12, Ne. ¼	Lappint	95	Drift, 50; sandstone, 45.
Otho	Sec. 7, center	Keyes' report	......	Drift, 57; gypsum, 1.
Elkhorn	Sec. 25, Sw. ¼	Lappint	70	Drift, overlying sandstone.
Elkhorn	Sec. 6, N. ½	Lappint	120	Drift and Coal Measures. No gypsum.
Clay	Sec. 8, Nw. ¼	Rasmusson & Stone	296	Drift, shale and 50 feet of limestone.
Elkhorn*	Sec. 32, Se. ¼	Rasmusson & Stone	252	Shale & 12 feet of limestone.

* Other wells of which records were obtained in Elkhorn township, were shallow and did not go through the drift.

RECORDS OF PROSPECT HOLES

Pleasant Valley township, southeast 1/4 Section 4.

		Feet	Inches
9.	Soil	3	
8.	Yellow clay	16	
7.	Blue clay	30	
6.	Red shale	4	
5.	Shales	30	
4.	Rock (undet.)	1	10
3.	Shale	9	
2.	Coal	2	7
1.	Black jack		8

On the same quarter section:

		Feet	Inches
6.	Soil	2	
5.	Yellow clay	17	
4.	Blue clay	25	6
3.	Red shale	2	6
2.	Gypsum	12	
1.	Shale	5	6

Douglas township, section 36, southeast 1/4 (on what is known as the Bassett farm).

		Feet	Inches
14.	Soil	2	
13.	Yellow clay	8	
12.	Blue clay and sand	36	
11.	Red sandy shale	30	
10.	Gypsum	1	
9.	Yellow shale		7
8.	Gypsum	17	7
7.	Shale	15	6
6.	Rock (undet.)	1	3
5.	Sandstone		6
4.	Coal		5
3.	Fire clay	5	1
2.	Shale	1	
1.	Brown sandstone	1	6
		119	9

On the southeast 1/4 of section 6, Otho township, on which were located the mines that supplied the Duncomb Plaster Mills, ten prospect holes gave the following records:

No. 1. 46 feet, all in drift
No. 2. 50 feet in drift and shale, 10 feet gypsum
No. 3. 45 feet in drift and shale, 15 feet gypsum
No. 4. 50 feet in drift and shale, 7 feet gypsum
No. 5. 50 feet in drift and shale, 4 feet gypsum
No. 6. 41 feet in drift and shale, 11 feet gypsum
No. 7. (In a hollow) 6 feet of drift, 11 feet gypsum
No. 8. 38 feet drift and shale, 6½ feet gypsum
No. 9. 54 feet drift and shale, 12 feet gypsum
No. 10. 45 feet drift and shale, 20 feet gypsum

Lees reports that an old mine shaft in the northwest quarter of section 3, Pleasant Valley township, went through about four feet of gypsum and that Mr. M. A. Hughett's barn well in the southwest quarter of section 36, Cooper township, went through a little gypsum, but the house well only 150 feet away encountered no gypsum.

Cemetery well

J. J. Meyer in drilling a well in the cemetery, Cooper township, section 17, penetrated a considerable body of gypsum. This is not surprising in view of the excellent exposures along Soldier creek, a little to the south.

Record of prospect holes drilled for gypsum in southwest quarter, section 27, Cooper township, Webster county, for W. J. Carter.

	Feet		Feet
No. 1		No. 6	
drift	55	drift	49
gypsum	20	red clay	3
No. 2		gypsum	21
drift	47	No. 7	
gypsum	23	drift	49
No. 3		red clay	1
drift	47	(record not clear)	6
gypsum	23	gypsum	21
No. 4		No. 8	
drift	48	drift	49
gypsum	24	red clay	5
No. 5		gypsum	21
drift	44		
red clay	3		
gypsum	23		

Hole No. 9 near the center of south line of northwest quarter, section 27, went from drift directly into Coal Measures clay. Near the northwest corner of this section twelve feet of gypsum was found in a well, and twenty-three feet of gypsum was located in a well in the southeast corner of the same quarter section.

In the south half of the northwest quarter of section 26, Cooper township, seven drill holes gave an average of twenty-two feet of gypsum. From two to five feet of red clay (Fort Dodge beds) occurs above the gypsum in most instances, and above this the drift averages about fifty feet thick.

Mr. C. H. Crutchman has drilled eighty-two holes on his farm in the west half of section 27, Cooper township, and found conditions quite like those reported above in the drillings for W. J. Carter in the same section. The thickness of the gypsum ranges from twenty-four feet, eleven inches, to two feet. It is generally covered by three to six feet of red clay (Fort Dodge beds) and lies beneath forty to fifty feet of drift.

Other well data listed by sections follow:

North half of northeast quarter of section 28, Cooper township, gypsum reported by C. H. Krutchman.

North half of southeast quarter of section 22, Cooper township, eight feet of gypsum reported by C. H. Krutchman.

Middle quarter of south half of section 24, Cooper township, gypsum reported in well by F. H. Pingel, thirteen feet found, with well ending in gypsum.

Northeast quarter of section 30, Cooper township, gypsum reported by F. H. Pingel.

Southwest quarter of section 36, Cooper township, gypsum reported in well by Mark Hughett.

Southwest quarter, section 19, Colfax township, no gypsum known, though wells penetrated to ninety-five feet and to one hundred and sixty-eight feet (H. Scharf).

Northeast quarter of section 30, Colfax township, wells over one hundred feet deep located no gypsum (J. F. Hogan).

Northwest quarter of section 29, Colfax township, wells eighty feet deep located no gypsum (E. T. Stake).

Southwest quarter, section 20, Colfax township, two wells one hundred feet deep, no gypsum (J. J. Hogan).

Northeast quarter, section 20, Colfax township, well one hundred and twelve feet deep, no gypsum (P. Ledeh).

Southwest quarter, section 29, Colfax township, well one hundred and fifty feet deep, no gypsum (Dr. J. W. Kime).

Reports are conflicting in regard to the finding of gypsum in the stockyards well at Industry.

Middle of south line of section 12, Cooper township, four or five feet of gypsum reported in eighty foot well (John Grebner).

Southeast quarter, section 11, Cooper township, well one hundred and thirty-five feet deep showed no gypsum (James Coughlin).

Southwest quarter, section 36, range 28 west, township 89 north, five holes from seventy to one hundred and six feet deep gave no gypsum, Coal Measures shales coming in directly under the glacial drift (Mr. Hughett's farm).

Cooper township section 8, N. E. ¼.
Well eighty-eight feet deep struck no gypsum.

Cooper township section 35, N. E. ¼
Five feet of gypsum was found in a well.

Cooper township section 2, S. W. ¼
No gypsum found in a well seventy feet deep.

Colfax township, section 5, middle of south line
Well eighty feet deep struck no gypsum.

Colfax township section 9, N. W. ¼
Well seventy-five feet deep struck no gypsum.

Colfax township section 9, S. W. ¼
Well 147 feet deep struck no gypsum.

Colfax township section 16, N. E. ¼
Well eighty feet deep struck no gypsum.

Colfax township section 9, The Gus Ming well, 90 feet deep struck no gypsum.

Colfax township section 21 N. E. ¼ of the N. W. ¼
Well sixty feet deep struck no gypsum.

Colfax township section 20 N. E. ¼
Well 160 feet deep struck no gypsum

Colfax township section 17, middle of north line
Well 160 feet deep struck no gypsum.

Colfax township section 19, well on middle of north line 180 feet deep struck no gypsum.

ST. LOUIS LIMESTONE

The limestone reported frequently in the earlier part of this chapter as occurring in localities along the river and along Soldier and Lizard creeks, has been consistently and without exception referred to the St. Louis stage of the Mississippian series. At certain points the St. Louis limestone is overlain by a sandstone layer and this in turn by marls. An interesting section of this sort may be seen a short distance above the mouth of Lizard creek.

Lizard creek section

		Feet
4.	Fossil-bearing marl	6
3.	Marl, gray, without fossils, containing many selenite crystals	40
2.	Sandstone, yellow, moderately hard, calcareous	2
1.	Limestone, slightly folded, in definite layers, in places brecciated	17

The first or lowest member of this series represents the St. Louis while Nos. 2, 3, and 4, though formerly regarded as belonging to the St. Louis, are now referred to the Ste. Genevieve.

Typical section

A typical section for the St. Louis in Webster county is found just at the northern edge of the gypsum area, on Des Moines river, in Cooper township, section 7, the southwest quarter.

		Feet	Inches
13.	Sand	5	
12.	Limestone layer	1	
11.	Limestone layer with persistent band of flint one inch thick	1	2
10.	Limestone layer	2	6
9.	Limestone layer	1	
8.	Limestone layer	1	
7.	Limestone, at some points massive and at others showing layers slightly distinguishable	4	
6.	Limestone layer, light color		1
5.	Limestone layer	1	
4.	Limestone layer	1	
3.	Sandstone in places containing a flint band one inch thick		6
2.	Limestone layer	1	6
1.	Sandstone, to water's edge	1	6

STE. GENEVIEVE

Directly above the St. Louis limestone at three or four points in the district under discussion lie beds of fossil-bearing marl and between them and the limestone is a sandstone layer, which lies unconformably on the limestone. Earlier reports describing the Fort Dodge gypsum area classified these marls and sandstones with the St. Louis. Weller and Van Tuyl[121] have recently pointed out the faunal similarity of these marls to the Pella beds in the southeastern part of Iowa.

Nickles and Bassler[122] and subsequently Weller,[123] pointed out the Ste. Genevieve affinities of the Pella, and there is substantial ground for referring the fossil-bearing marls described on pages 146 and 154 to the Ste. Genevieve.

121Iowa Acad. Science, Vol. XXII, p. 241.
122U. S. Geol. Survey Bull. 173, pp. 166 and 188.
123Jour. Geology, Vol. XVII, p. 278, 1909.

The following quotation from the paper of Weller and Van Tuyl[124] is interesting in this connection:

"In his report on the geology of Lee county Keyes described a fine-grained, compact limestone at the top of the St. Louis formation, resembling lithographic stone in texture. Gordon reported a similar limestone characterized by **Spirifer littoni** (**Spirifer pellaenis** Weller) and **Pugnax Ottumwa** at the same horizon in Van Buren county. Bain subsequently recognized this member in Keokuk county and named it the Pella because of its typical development at the town of this name in the neighboring county of Marion. This name has been adopted by Savage in his geology of Henry county and by Miller in the Marion county report. Until 1900, when Nickles and Bassler referred the Pella to the Ste. Genevieve upon the basis of its bryozoan fauna, the St. Louis age of the formation was accepted without question. Weller subsequently pointed out the Ste. Genevieve affinities of the Pella fauna in 1909, and recent field studies have now likewise demonstrated that the Pella is formationally distinct from the underlying St. Louis, it being separated from that formation by a disconformity and by a characteristic basal sandstone in every Iowa locality which has come under observation.

"**Areal Distribution.**—In general, the exposures of the Pella beds in Iowa are confined mainly to the southeastern part of the state. In the belt of Mississippian rocks, which extends northwestward from this region, the higher formations of the system are concealed by the Coal Measures, except for locally exposed areas in Story, Webster and Humboldt counties, where the overlying beds have been removed by erosion. Little is known as to the extent of the Pella in this direction, but the finding of a good Pella fauna by Wilder in certain marls overlying the St. Louis limestone in Webster county indicates that the Pella seas extended at least as far northward as Fort Dodge."

The exposures of the St. Louis and Ste. Genevieve along the river above Fort Dodge, along Lizard creek and near Kalo, are shown on the geological maps.

Exposure near Kalo

The exposure near Kalo is one-fourth mile below the Minneapolis and St. Louis railroad bridge, about half a mile below the Vincent Clay Works, in Pleasant Valley township, section 5, the southwest quarter. Here the marl with typical brachiopods occurs above the St. Louis limestone, which

124Iowa Acad. Science, Vol. XXII, p. 241.

appears in the river bed. Half a mile farther down stream in section 8, the northeast quarter, the limestone appears for a thousand feet along the river. Above five feet of solid stone an equal thickness of marl is found.

The exposures along the lower course of Lizard creek have been described in the earlier part of this chapter. Shales and marls of the Ste. Genevieve that occur farther up the creek are described by Lees as follows:[125]

North Lizard exposure. No. 29 on map

"About four hundred yards above the junction of North and South Lizard creeks, on the east bank of North Lizard, there is an exposure of the gray-green shale which rises twenty-five or thirty feet above the stream. Over this shale lies fifteen to twenty feet of red shale. At several horizons in the gray-green shale there are harder limy bands which contain large numbers of fossil brachiopods. The contact of the red shale with the gray is quite sharp and lies just above a layer of fossiliferous yellow limestone.

Douglas township outcrops.

"The next exposures on this fork, and so far as is known to the writers the last ones, are a group five miles up the valley and in the southeast quarter of section 8, Douglas township, about one-fourth mile below the Minneapolis and St. Louis railroad bridge, on the north bank of the stream. Here a small tributary ravine has been cut through six feet of yellow and green shale, below this through five feet of red and green shale, beneath which is exposed two feet of gray sandstone or sandy limestone, then five feet of shaly material beneath which in turn two feet of green shale is seen above the stream level. Just down the main valley a few rods is an exposure of ten feet of yellow and brownish red clay shale, under which is six feet of red shale which lies on gray sandstone which rises six feet above the creek. The red shales of these exposures are for the most part true clay shales, although some are finely sandy. Lithologically they are the equivalent of the red shales overlying the fossiliferous gray-green marls seen in the abandoned clay pit and elsewhere upstream as far as the exposure just above the forks. None of the beds at this locality yielded any fossils nor were there found any of the nodular limestone bands which are the fossiliferous members of the exposures farther downstream. Black shales probably Coal Measures are said to be present in the valley walls. Along the ravine to the north there are exposed at intervals for nearly one-half mile pink

[125] Iowa Acad. Science, Vol. XXV, pp. 601, 616, 1918.

and gray clay shales which rise at least twenty feet above the water."

PENNSYLVANIAN SERIES

DES MOINES STAGE

The productive Coal Measures of Iowa belong to the Des Moines stage of the Pennsylvanian series. The Des Moines beds underlie the drift in most of the central and southern part of Webster county, the principal exception being the area where the gypsum with its associated shales, known collectively as the Fort Dodge beds, intervenes.

Nature of Coal Measures

The Coal Measures consist of shale, coal, sandstone, with thin beds of argillaceous limestone and limonite. The shales are fissile, in many cases arenaceous, and generally free from lime. They differ in color from very dark gray to yellow. Sections showing beds of shale belonging to the Des Moines stage appear in several of the earlier pages of this chapter. These beds are fairly constant in their physical characteristics and their presence has always been recognized within the district under consideration. In this region they are in every way distinct from the members of the Mississippian series, which they invariably overlie unconformably, except at points where the Des Moines beds were removed prior to the deposition of the Fort Dodge beds, where, of course, the Fort Dodge beds themselves rest on the Mississippian. In the southern part of the area under consideration two rather constant features of the Des Moines beds are of special aid in studying structural problems. There is the bed of gray sandstone which, at the Vincent clay pit; at the entrance to the depression leading to the Plymouth mines; along the river and along the Interurban railway track, lies about twenty feet below the gypsum, though at one or two points the gypsum lies directly on it. Secondly, there is the thin bed of fossiliferous limestone that generally lies about twenty feet below this sandstone. A typical section through the Fort Dodge beds and Coal Measures to the St. Louis limestone is given on page 157 where a drill hole in Cooper township, section 33, is recorded. The record of the well in Elkhorn township, section 3, given on page 156 is very similar.

PERMIAN

FORT DODGE BEDS

The gypsum is so characteristic that it is easily recognized wherever it occurs. The highly colored shales associated with the gypsum are quite definite in their nature and very little if any confusion has arisen in their classification. Where they are associated with the gypsum their identification is generally easy. At a few points an element of uncertainty arises from the fact that the Coal Measures shales are locally rather highly colored.

Character of Beds

The heaviest body of the bright shales associated with the gypsum is found at the north abutment of the Soldier creek viaduct. Here fifty[126] feet of the pink-red shales with characteristic sandy streaks is exposed.

In 1916 Lees noted a conglomerate in the ravine followed by the Fort Dodge, Des Moines and Southern railroad, on the west side of the river in Pleasant Valley township, section 6, the southwest quarter, and Elkhorn township, section 12, the northeast quarter. A generalized section of this ravine is given on page 150. It shows ten or fifteen feet of gypsum separated by six inches of clay from a conglomerate layer one to two feet thick. This conglomerate is illustrated in figure 13. The conglomerate rests on a bed of red clay twelve feet thick beneath which are gray sandstones and shales. The conglomerate forms the basal member of the Fort Dodge beds. Since this conglomerate contains fossils and no other fossils have been found in the Fort Dodge beds, it has received careful study.

Lees' paper[127] discussing this conglomerate is quoted below.

A New Basal Conglomerate.—During the prosecution of field study of the gypsum for the Iowa Geological Survey the writer found immediately beneath the gypsum in several places a basal conglomerate which has not heretofore been described in reports on the region. The locality where this conglomerate is best developed is in a ravine on the west side of Des Moines river opposite Two Mile creek about three miles south of Fort Dodge. The Fort Dodge, Des Moines and Southern railway

126Keyes in Iowa Acad. Science, Vol. XXIII, p. 108, reports: "75 feet of the pink shales which directly overlie the gypsum," at this point and it may be assumed that he saw the section under exceptionally favorable conditions at the time of excavation of the viaduct. Drift apparently has washed down over part of the exposure to which he refers.

127Iowa Acad. Science, Vol. XXV, pp. 587-591.

extends along this ravine and has exposed the conglomerate in some of its cuttings. In the lower part of the ravine the gypsum is seen to be on the black or dark colored Coal Measures shales. In places the contact is direct while in other places about six inches of clay, evidently residual, intervenes. Perhaps one-half mile up the ravine there is exposed beneath the gypsum a reddish or grayish conglomerate one to two feet thick. The pebbles are mostly limestone, fairly well smoothed by attrition, and are rather small, the larger ones being not much over an inch in diameter. Under the conglomerate lie

FIG. 13.—Conglomerate which appears at the base of the Fort Dodge beds in the ravine which is followed by the Fort Dodge, Des Moines and Southern railroad on the west bank of the river. This conglomerate contains the only fossils ever found in the Fort Dodge beds.

the shales of the Des Moines stage locally colored red or lighter shades. At other places near by the conglomerate outcrops immediately beneath the drift. The gypsum either has been removed by erosion or solution or was not deposited. The significant feature about this conglomerate, however, is its fossil content, and this it is which makes it of peculiar value in relation to the gypsum. Professor Thomas of the Department of Geology of the State University visited the gypsum region with the writer on a later trip and a number of fossils were collected from the conglomerate. Mr. Thomas after studying this collection and comparing it with type forms wrote as follows:

"The basal conglomerate fauna is very evidently of Missourian age although I am not ready to say so unequivocally since so many Pennsylvanian forms have a habit of continuing on into the Permian. I have compared the unquestionably identified species with Pennsylvanian and with Permian lists and all point to the former rather than to the latter. Not a trace of anything Mesozoic occurs in the material. Some of the specimens show evidence of wear as from rolling but they do not seem to have been transported far. Here is the list:

Squamularia perplexa (McChesney).
Pugnax osagensis (Swallow).
Fusulina secalica Say=F. cylindrica Fischer.
Productus cf. longispinus Sowerby.
Rhombopora lepidodendroides Meek?
Zaphrentis (unidentified).
Stem segments and plates (?) of unknown crinoids.

"The Rhombopora has suffered from wear so that the characteristic markings, if they were ever present, are rubbed off. There is no question about the Fusulina. I sectioned a few, they are as good specimens as one could wish for."

The nearest known rocks of Missouri age are in Carroll, Crawford, and Monona counties. In former time the northward extent undoubtedly was greater. Cretaceous rocks are present only a few miles to the west of Fort Dodge in Calhoun and Pocahontas counties. In spite of the softness of these rocks fossils certainly could be transported as far as the gypsum region and in fact they are found in the drift at considerable distances from the original strata. There are no known strata in northwestern Iowa west of Webster county intermediate in age between the Missouri and the Cretaceous. The presence of Missouri life forms in the conglomerate of the gypsum region proves it to be of post-Missouri age, while the entire absence of fossils of Cretaceous or later age argues strongly for a post-Missouri-pre-Cretaceous age for the conglomerate and for the associated gypsum and the shales and sandstones which in some localities overlie it.

Doctor Sidney L. Galpin of the Department of Geology of Iowa State college informs the writer that a similar fossiliferous conglomerate underlies the gypsum beds of Kansas, which are well known to be of Permian age.

The other locality where this conglomerate was found is at the pit of the Vincent Clay Products Company at Shady Oaks station on the Fort Dodge, Des Moines and Southern railway. This is at the mouth of Two Mile creek on the east bank of Des Moines river directly opposite the ravine in which the previously described outcrops occur. Here the conglomerate is absent from some places while at others it is a foot or a foot and a half thick. It is red and gray and most of the pebbles are less than one-half inch in diameter. Parts of the conglomerate are really a coarse sandstone. Fossils were found in streaks and pockets of the coarser materials.

A noteworthy feature in this pit as well as in several others is the fact that the upper few feet of the Coal Measures shales just under the gypsum is highly colored, red, blues, purples, and light grays predominating. These lighter colors grade into black below. Whether this lighter coloration is inherent in the shales or is due to the chemical action of the dissolved gypsum as it percolates downward is not clear.

GEOLOGICAL AGE OF THE FORT DODGE GYPSUM

Aside from the fossil evidence in the conglomerate just described there is no new light on the geological age of the Fort Dodge beds. The writer assigned these beds to the Permian in his report on Webster county[128] and the statements there made still seem to hold good, though in the light of present knowledge less emphasis should be laid on aridity as a factor governing gypsum deposition. They may be quoted here:

The fact that the gypsum and the red shales lie unconformably on the Coal Measures is good ground for believing that if they belong to the Paleozoic era they were formed near its close, during the Permian. The Permian beds of Kansas, Indian Territory and Texas, which contain quantities of gypsum, are so highly and so characteristically colored that they are known as the "red beds". These red beds like the red shales and gypsum of Iowa are nearly destitute of fossils, due probably to the fact that the climatic conditions favoring deposition of gypsum were hostile to organic life. Aridity is the climatic characteristic most essential for great deposits of gypsum, and the redness of the sandstones and shales usually accompanying gypsum deposits of all ages and localities may fairly be assumed to be an effect of climate, direct or indirect, on the iron content of the soil. All of these considerations, namely, the arid climate that prevailed during the Permian, shown by great gypsum deposits associated with red shales occurring in both Europe and America, and the striking resemblance which the series bears to the Permian only 300 miles to the west, carry great weight. The Iowa series might reasonably be interpreted as an outlier of the Permian of Kansas and Indian Territory. During the long interval between its deposition and that of the drift which now protects it erosion had an abundant oppor-

[128]Iowa Geol. Survey, Vol. XII, pp. 111-114.

tunity to remove the Permian from the intervening territory. The gypsum was doubtless protected by heavy beds of the red shales, for had it been exposed long it must have yielded to the solvent and erosive action of water.

It is possible to refer the gypsum to the Triassic or to the Cretaceous. Like the Permian, the Triassic of the west is red and contains large deposits of gypsum, notably those of the Black Hills. Known outcrops of Triassic strata occur only far to the west of the area under consideration, much farther west than the most eastern exposures of recognized Permian in Kansas. While this fact favors a reference of the Iowa gypsum to the Permian rather than the Triassic, the fact that the Permian of Kansas rests conformably on the Coal Measures while the gypsum of Iowa does not, throws a certain amount of weight the other way.

The claims of the Cretaceous have been considered in previous reports on the region.[129] Reference to the geological map of Iowa shows that Cretaceous deposits are present throughout the greater part of northwestern Iowa and that they approach within thirty miles of Webster county, at Auburn in Sac county, where they appear as chalk. The Cretaceous in Iowa consists of sandstone of the Dakota stage, and shales, limestone and chalk of the Colorado stage. Sandstone, shales and limestone have yielded abundant fossils which definitely fix their age. Other things being equal, it would be somewhat more natural to regard the Webster county gypsum series as an outlier of the Cretaceous than of the Permian which is farther away, yet the distance is not so great as to render a correlation with the Permian in any degree improbable if the preponderance of other evidence favors such a view. A review of Cretaceous climatic conditions is first of all necessary, for if aridity is a more striking characteristic of the Permian than of the Cretaceous, the Cretaceous age of the gypsum can hardly be established. The Dakota sandstone is in places red, but this color does not everywhere prevail and it does not characterize the Cretaceous shales and limestones in any degree. The Dakota sandstone abounds in fossils, as does the limestone of the Colorado stage, in which Inoceramus labiatus is found in great numbers. The Benton shales, while not so rich in fossils as is the limestone. contain Ostrea congesta, Prionocyclus wyomingensis and other species, none of which are brackish water forms. They contain also some selenite, but in view of the fossil contents of the shales it is probable that the selenite was not formed by precipitation from concentrated brine at the

[129] Iowa Geol. Survey, Vol. III, p. 290.

time that the shales were laid down, but is due to subsequent chemical reaction in which sulphuric acid, generated perhaps from iron pyrites, converted part of the lime carbonate of the shales into the sulphate. In barrenness of fossils, in color and in association with gypsum the red shales which accompany the Iowa gypsum resemble the Permian of Kansas much more than they do the Cretaceous shales of Iowa. The presence of chalk in Sac county, close to what must have been the Cretaceous shore, indicates that for a time sediments from land were at a minimum and organic sediments unmixed with land waste were able to accumulate near the shore. This would indicate an absence of the barren surface usually attending aridity, or the absence of elevation, or both, so that climatic conditions favoring deposits of gypsum are not implied by the chalk of the Cretaceous. Regions devoid of rainfall are characterized by windstorms of great violence capable of transporting much earthy material as dust and carrying it out to sea where it would ultimately be deposited. The arid regions of America are subject to brief but violent rain storms during which erosion is vigorous on the surface barren of vegetation. Low land surfaces covered with an abundant vegetation are most favorable for pure chemical and organic accumulations in the neighboring seas. The great purity of many gypsum deposits presents a difficulty for this very reason, for the land must have been barren during the concentration of the sea water and conditions favorable for dust storms seem likely to have prevailed. Microscopic examination of the Iowa gypsum reveals particles of sand scattered through the gypsum, probably by wind, but the total amount is small, amounting to about one per cent of the whole.

STRUCTURAL PROBLEMS CONNECTED WITH THE FORT DODGE BEDS

Unconformities

The structural feature that stands out most prominently and which has been emphasized by every student of the Fort Dodge beds, from Worthen in 1856 on to the present, is the pronounced unconformity that exists between Fort Dodge beds and the Coal Measures.

The unconformity between the Mississippian beds (Ste. Genevieve and St. Louis) and the Coal Measures also is a striking phenomenon. The relationship existing between the Mississippian, the Coal Measures, and the Fort Dodge beds was shown by Keyes in a diagram that has become a classic[130] and is reproduced as figure 14.

[130] Iowa Geol. Survey, Vol. III, p. 269. Second annual report, 1893.

The curious variations in the strata seen along the bed of Soldier creek, described earlier in this chapter, are accounted for by the uneven floor of the Mississippian on which the Coal Measures were laid down by the erosion to which the Coal Measures were subjected prior to the deposition of the gypsum.

Fig. 14.—Keyes' diagram showing relationships between the St. Louis limestone, the Coal Measures and the Fort Dodge beds.

Fort Dodge Basin

The Fort Dodge beds seem to have been laid down in an oval basin whose longer axis extended from northeast to southwest. The proof of the existence of this basin is found in the relationships of the Fort Dodge beds to the underlying formations in the restricted area within which these beds lie, which relationships have been set out fully earlier in this chapter. They are shown graphically in the sections on Plate VI.

Keyes' earlier views

Keyes in 1895[131] regarded the gypsum as a basin deposit, laid down in a long estuary extending from northeast to southwest, in the Cretaceous (Niobrara) sea. In a recent paper[132] Keyes postulates a remarkable series of faults in the Mississippi Valley region and in the series introduces faults in the Fort Dodge region which he believes explain the position of the gypsum and its preservation from erosion. He regards the gypsum as of Miocene age though it is not clear on what grounds this correlation is made.

Keyes' later hypothesis

Fort Dodge beds in Tile Pit section

He finds evidence of faulting in the Soldier creek exposures and particularly between Kohl's brewery section at the mouth of this creek and the Fort Dodge Brick and Tile pit section

[131] Iowa Geol. Survey, Vol. III, pp. 285-290.
[132] Iowa Acad. Science, Vol. XXIII, pp. 103-112, 1916.

on the river one-fourth of a mile farther north. Keyes finds no sign of Fort Dodge beds in the Tile pit and accounts for it by assuming a fault that passed between the pit and the bluffs near the mouth of Soldier creek. Gypsum and its associated pink shales, probably in place or nearly so, have been found in the Tile pit and the Fort Dodge shales are found in at least six places between the mouth of Soldier creek and the Tile pit. The difference in elevation, perhaps fifty or sixty feet, is not more than can be readily accounted for by basin conditions or by slight folding, when it is remembered that the localities under consideration are fifteen hundred feet apart.

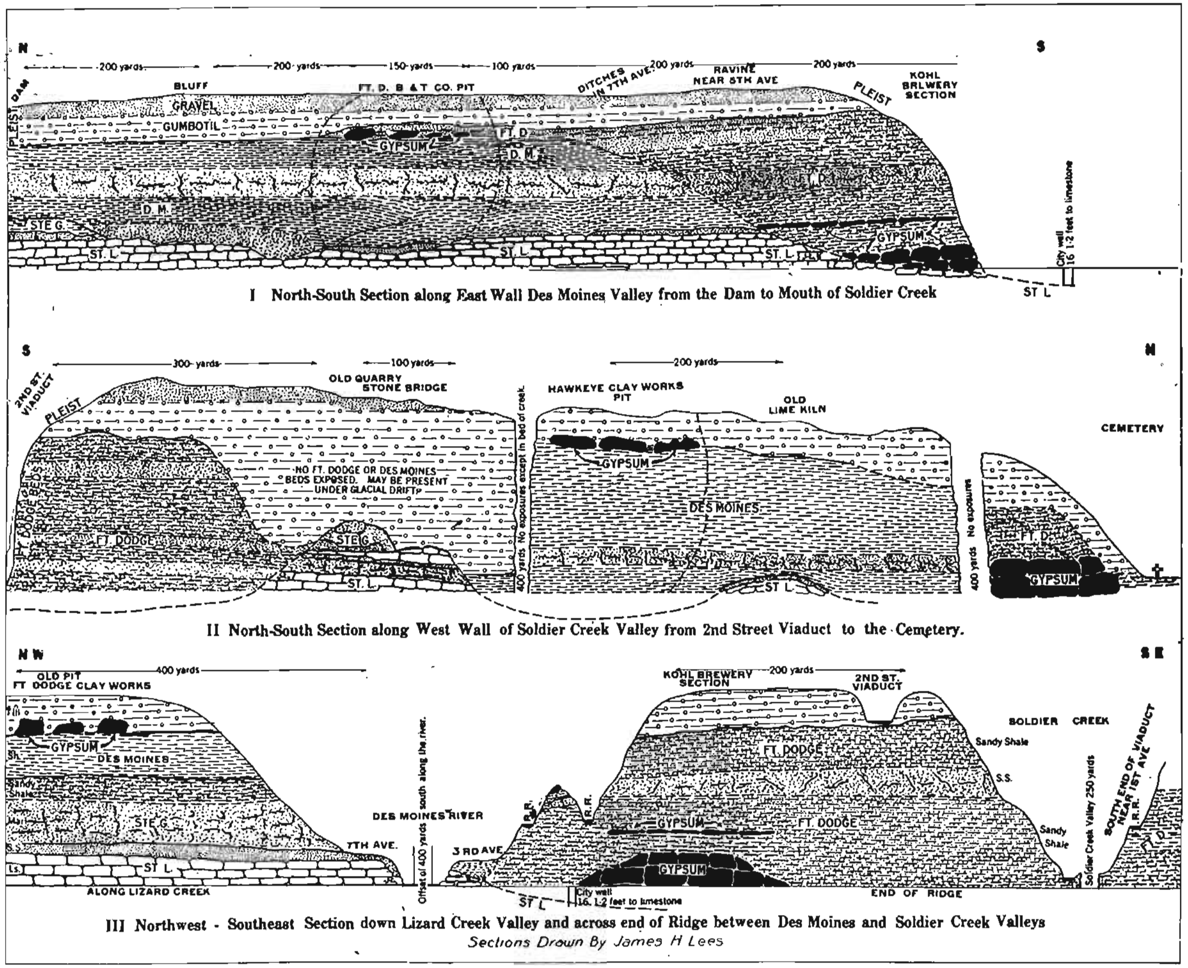
The Fort Dodge beds certainly are present in the old pit at the abandoned Fort Dodge Clay Works, across the river and a little above the mouth of Soldier creek; and they are present in the north pit of the same plant a thousand feet up Lizard creek, on its left bank. At both of these points the Fort Dodge beds are considerably above the same beds as shown at the old Kohl brewery section and their elevations correspond rather well with the same beds in the Fort Dodge Brick and Tile pit. If a fault running northeast to southwest and in the general direction of Soldier creek is needed to explain the difference in elevation between the Fort Dodge beds at the mouth of Soldier creek and in the Tile Company's pit, there is apparently the same need of postulating another fault running at right angles to the first one, and in the general direction of the river, to account for the difference in elevation between the Fort Dodge beds in the Kohl brewery section and in the Fort Dodge Clay Works pit.

Fort Dodge beds in Clay Works section

It seems simpler to assume a basin whose sides rise gradually to the north and to the west as well. If Keyes' hypothesis of an east-west, or a northeast-southwest fault were correct, the St. Louis limestone on Lizard creek should be considerably higher than the limestone along Soldier creek, and along the river south of Soldier creek. While the surface of the St. Louis limestone is irregular, as has been shown, it is no higher on Lizard creek than on Soldier creek or along the river.

A basin probable

The stratigraphic peculiarities of the Soldier creek basin, set



Cross sections along Des Moines valley and Soldier and Lizard creeks.

out in detail in the first part of this chapter, are all readily explained by the two unconformities which are so apparent to all students of the region.

The gypsum in the old pit of the Fort Dodge Clay Works on Lizard creek, and at the cemetery north of Soldier creek, lies north of the fault line postulated by Keyes. The inference that is naturally drawn from his paper is that the gypsum is confined to the area south of this fault line, whereas gypsum outcrops on Lizard creek north of the line he has drawn, it appears as large blocks in the pits of the Hawkeye Clay Works in Soldier creek valley and of the Fort Dodge Brick and Tile Company in Des Moines valley and it is reported in well drillings north of Fort Dodge. It has been exposed also in ditches on the Hawkeye Highway along the west wall of Des Moines valley opposite the Fort Dodge Brick and Tile Company's pit.

ORIGIN OF THE GYPSUM

In chapter III the conclusion is reached that beds of commercial gypsum are not all alike as to origin. The evidence presented also leads to the belief that secondary concentration has played a much larger role than has generally been assigned to it. Gypsum has in many cases been deposited in limited quantities in clays, shales and limestones, and subsequently dissolved and concentrated in basins by ground water.

The marls of the Ste. Genevieve, the limestones of the St. Louis, and the shales of the Coal Measures in Webster county contain gypsum in considerable quantities. On weathered exposures of the shales and marls at numerous points selenite crystals can be gathered in abundance.

Possible source of the gypsum

Analyses of the St. Louis limestones and interbedded shale from the mouth of Lizard creek give[133]

	PER CENT
Upper layer, 2 feet	
Carbonate of lime	88.75
Sulphate of lime	00.28

[133]Analyses by Lundteigen, Peerless Portland Cement Co.

Next layer, shale, 2 feet	
Carbonate of lime	53.25
Sulphate of lime	2.46
Next layer, 2¼ feet	
Carbonate of lime	88.75
Sulphate of lime	00.17

The conditions that would give rise to beds of gypsiferous shales, marls or limestones occur a dozen times to one occurrence of conditions that make possible by primary deposition beds of commercial gypsum.

The following analyses of Ste. Genevieve shales from the banks of Lizard creek in section 8 of Douglas township, Webster county, however, show no gypsum.

Constituent	Per cent	Per cent
Silica (SiO_2)	73.99	78.35
Water at 105°C.	1.67	2.91
Water from 105° to red heat	4.19	3.54
Alumina (Al_2O_3)	17.70	14.00
Iron Oxide (Fe_2O_3)	.90	.60
Calcium Oxide (CaO)	1.66	.50
Total	100.11	99.90

Analyst: F. S. Mortimer.

On the other hand the Mississippian marls along Des Moines river above Fort Dodge, near the site of the dam, contain large quantities of gypsum crystals. The Mississippian in many localities in the United States and elsewhere contains extensive deposits of gypsum, and it would not be remarkable if it furnished material for concentration under conditions that existed in the Permian.

The Fort Dodge beds may represent a remnant of gypsiferous beds laid down in Permian time and the gypsum may have been disseminated through Permian shales which connected the Iowa area with Permian areas in Kansas.

The concentration of disseminated gypsum is greatly aided in arid climates by efflorescence. The soil water is constantly rising to the surface carrying with it mineral matter with which it has come in contact. On the surface the water evaporates and the mineral is deposited, to be caught up by the winds to make dunes, or to be redissolved by the next rain and carried to some nearby basin or to some stream which ultimately bears it to the ocean.

The possibility that the Fort Dodge gypsum was deposited in an arm of the ocean under conditions like those described in chapter IV as existing at certain points along the Caspian sea may be admitted. At the same time the probabilities are that the gypsiferous beds of the Ste. Genevieve, the St. Louis and the Coal Measures furnished material which was reworked by ground waters, and redeposited after the manner of the gypsum lakes of Australia described in chapter IV.

EXTENT OF THE FORT DODGE GYPSUM BEDS

In his report on Webster county the writer stated that[134]

"The well data and records of prospect holes neither positively confirm nor deny the suggestion of Keyes that the gypsum extends on from the Fort Dodge region through the southwestern part of the county and connects with the chalk deposits that are found near Auburn in the southeast corner of Sac county. In the southwestern part of the county most of the wells do not go through the drift and few positive data in regard to the formations under the drift were attainable. Gypsum was not definitely reported by any well driller farther west than the Bassett and the Poor farms, two miles west of the river. Evidenees of gypsum as far west as Moorland and Callender are too uncertain to make it wise to extend the gypsum area to those towns. A prospect hole drilled for F. J. Deischmidt just east of Moorland by the Jasper county Coal Company in search of coal is said to have penetrated gypsum. The parties who possessed primary knowledge of this prospect hole have died and it is impossible to corroborate the report. North and east the gypsum area may now be extended beyond the limit which was definitely known when Keyes made his report. At Vincent gypsum was reported by those who drilled the creamery well. A number of reliable persons examined the material brought up by the bucket and pronounced it gypsum. In order to verify as far as possible these statements water from this well, which was said to stop just below the gypsum, was analyzed with these results:

Calcium oxide	226 pts. per million
Sulphur trioxide	302.5 pts. per million
Equal to calcium sulphate	528.5 pts. per million

"The high percentage of calcium sulphate, one part in two

[134]Iowa Geol. Survey, Vol. XII, p. 108.

thousand, would indicate the existence of gypsum in the neighborhood.''

In 1917 an effort was made to verify the statements in regard to the creamery well but the creamery had long ceased to exist and even the existence of a well that passed through the glacial drift was questioned. The analysis of the water from this well, however, was actually made with results as stated.

Gypsum is reported in two wells in the northeastern part of Colfax township, in sections 8 and 18 (see table on page 159). These wells are four miles away from Vincent, but they lend a little support to the reported occurrences in the vicinity of that village. Recent well data from other points in Colfax township render doubtful the accuracy of these records. While the area mapped as probably containing gypsum, and published in the report on Webster county, may be correct, a more conservative estimate is shown on the map that accompanies this report. The Fort Dodge beds probably underlie an area twenty-five or thirty miles in extent. Perhaps not more than half of this area will prove productive, on account of preglacial erosion which has channeled the gypsum deeply along the river and the larger creeks.

Duration of gypsum supply

The average thickness of gypsum that can be mined for plaster in the Fort Dodge field is ten feet and the estimated yield per acre is 20,000 tons after allowing sufficiently for gypsum left as roof and pillars.

The output of the Fort Dodge district is now about 500,000 tons a year. This means that gypsum is annually removed from twenty-five to thirty acres.

Assuming that the output remains at the present level, the gypsum supply in the Fort Dodge region probably is sufficient for more than two hundred years. If the production continues to increase in the ratio that it has increased during the last twenty years[135] the supply will be exhausted in one or two generations. It is hardly probable that the rate of increase of recent years will be maintained. An annual average gain of 10 per cent is perhaps conservative. This means an output of a million tons in 1931 and two million tons in 1941. After

[135]From 100,000 tons to 500,000 tons, or 500 per cent.

twenty years, more or less, when gypsum products have been fully applied to the many fields for which they are adapted, the curve of increase will flatten and conform to the curve which represents the increase in population.

The Fort Dodge field can probably sustain an output of two million tons a year for seventy-five years.

THE CENTERVILLE FIELD

Deep drilling near Centerville in Appanoose county during the fall of 1910 revealed an interesting deposit of gypsum at that point.[136]

The Scandinavian Coal Company put down a test hole with a core drill to a depth of 550 feet and between 537 and 547 feet found five feet each of gypsum and anhydrite. A study of the log of this drill hole has resulted in the following classification of the formations penetrated.

Group	System	Series	Stage	Formation
Cenozoic	Quaternary	Pleistocene	Kansan drift	
Paleozoic	Carboniferous	Pennsylvanian	Des Moines	Henrietta limestone shale Cherokee shale coal limestone
		Mississippian		limestone shale sandstone gypsum anhydrite

The detailed record of this hole follows:

136A new Gypsum Deposit in Iowa: U. S. Geol. Survey Bull. 580E, pp. 59-64, 1914.

Driller's log of hole of Scandinavian Coal Co., Centerville, Iowa

	Thickness Ft.	Thickness In.	Depth Ft.	Depth In.
Filled ground	3	0	3	0
Yellow clay	28	0	31	0
Limestone	1	0	32	0
Limestone with shale	8	0	40	0
Soft blue shale (banded)	10	0	50	0
Soft blue shale	14	0	64	0
Limestone	3	0	67	0
Sandy shale[a]	21	0	88	0
Old workings	4	0	92	0
Fire clay	2	0	94	0
Limestone	1	6	95	6
Soft clay shale	1	6	97	0
Dark shale	9	0	106	0
Gray shale	7	0	113	0
Fossiliferous shale	1	0	114	0
Black shale	3	0	117	0
Gray shale, very soft	2	0	119	0
Gray shale	13	0	132	0
Black shale	2	6	134	6
Soft clay shale	15	6	150	0
Shaly sandstone	38	0	188	0
Sandstone	1	0	189	0
Black shale	2	0	191	0
Coal		2	191	2
Gray shale	8	2	199	4
Black shale		8	200	0
Coal	1	0	201	0
Limestone	1	6	202	6
Soft clay shale	7	6	210	0
Clay shale		10	210	10
Limestone	2	0	212	10
Black shale	2	10	215	8
Black shale	9	2	225	2
Limestone	4	0	216	0
Coal		10	226	0
Fire clay	1	0	227	0
Clay shale	2	0	229	0
Soft blue shale	3	0	232	0
Soft clay shale, gray	1	6	233	6
Blue shale	3	6	237	0
Black shale	1	4	238	4
Soft clay shale, gray		8	239	0
Blue shale	3	0	242	0
Blue shale with bands of red shale	1	6	243	6
Blue shale	3	8	247	2
Black shale	4	6	251	8
Coal	1	8	253	4
Black shale		8	254	0
Gray shale	6	0	260	0
Black shale	4	0	264	0
Clay shale	8	0	272	0
Gray shale	13	0	285	0
Sandy shale	4	6	289	6
Sandstone	2	6	292	0
Black shale	2	0	294	0
Blue shale	6	0	300	0
Gray shale	5	0	305	0
Sand shale	2	0	307	0
Red and blue shale	8	6	315	6
Blue shale	4	6	320	0
Black shale	0	6	320	6
Gray shale	3	9	324	3
Black shale	1	0	325	3
Coal		2	325	5
Black shale		6	325	11
Sandy shale	15	3	341	2
Coal	1	5	342	7
Sandy shale	4	5	347	0
Sandstone	5	0	352	0
Gray shale	3	9	355	9
Black shale	2	9	358	6
Gray shale	6	0	364	6
Dark shale	2	6	367	0
Gray shale	5	0	372	0
Black shale	9	0	381	0
Sandstone	7	0	388	0
Sandy shale	2	0	390	0
Black shale	3	0	393	0
Gray shale	12	6	405	6
Black shale		10	406	4
Coal (A)		8	407	0
Gray shale	4	0	411	0
Blue shale	4	0	415	0
Coal (B)		3	415	3
Blue shale	3	9	419	0
Clay shale	2	0	421	0
Gray shale	6	0	427	0
Red and gray shale	2	0	429	0
Gray shale	1	0	430	0
Clay shale	2	0	432	0
Gray shale	7	0	439	0
Shaly limestone	6	0	445	0
Limestone	14	0	459	0
Lime shale	9	6	468	6
Sandstone	8	6	477	0
Limestone		6	477	6
Lime shale	6	6	484	0
Limestone	16	0	500	0
Conglomeration of sand and limestone	6	0	506	0
Limestone with spots of shale	17	0	523	0
Limestone	14	0	537	0
Anhydrite, compact	5	0	542	0
Gypsum, white, crystalline	5	0	547	0
Limestone, dolomitic, buff	2	3	549	3
Green shale		9	550	0

This log has been interpreted as follows:

Correlation of log of Scandinavian Coal Co.'s hole at Centerville, Iowa

	Feet
Quaternary: Drift	31
Carboniferous:	
Pennsylvanian: Des Moines group:	
Henrietta formation: Limestones and soft blue shales	36
Cherokee shale: Blue, gray, and black shale, sandstone, several thin seams of coal, and some limestone	372
Mississippian: Chiefly limestone, lime shale, shaly limestone, some sandstone, gypsum and anhydrite	111
	550

[a] The driller's logs of holes 2 and 3 show no shale on top of the old workings of the Mystic bed; the roof is limestone.

The geology of the region is presented fully in the report on Appanoose county by H. F. Bain, published by the Iowa Geological Survey.[137] Except in the deeper valleys the region is covered with Kansan drift. The drift rests on rocks of the Des Moines stage of the Pennsylvanian series. The upper part of the Des Moines contains the Mystic coal which is one of the most extensively developed beds in Iowa.

Geology of the region

The rocks below the Pennsylvanian are not exposed in Appanoose county and are known only from drill records. The deepest of the three deep holes put down for water at Centerville gave the following section:[138]

Record of deep well at Centerville, Iowa

	FEET
Quaternary: Drift	90
Carboniferous:	
Pennsylvanian: Shales, coal and coaly shale, and a few thin seams of limestone	436
Mississippian: Chiefly limestones and shales	574
Devonian: Limestone and shales	260
Silurian: Limestones, shales, and sandstones	180
Ordovician: Dolomites, limestones, sandstones, and shales	955

This well reached a depth of 2,495 feet and no gypsum was recorded. The log of one of the other deep wells, however, states that at a depth of 600 feet, 15 feet of white sand was found. The material reported as white sand may have been gypsum or anhydrite. This well is located more than half a mile northeast of the test hole in which gypsum was first discovered.

Deep well at Centerville

Shortly after the discovery of gypsum at Centerville, two additional core drill holes were put down. One was located 1200 feet southwest of the original hole and at a somewhat lower elevation. The hole reached a depth of 563 feet, which brought it twenty or thirty feet below the level of the bottom of the gypsum already known. No gypsum was found. A third hole was drilled 1700 feet northwest of the original hole and here nineteen feet of excellent gypsum was found, beginning at 572 feet below the surface. Recently additional drill-

137H. F. Bain, Geology of Appanoose County: Iowa Geol. Survey, Ann. Rept., Vol. V, pp. 378-394.

138Iowa Geol. Survey, Ann. Rept., Vol. XXI, p. 937.

ing has been done, but the results are not available for publication.

The limestone directly above the gypsum is highly crystalline and very porous. The thickness varies from fourteen to twenty feet. It presents numerous flat cavities partly filled with calcite crystals.

The characteristics of the Centerville gypsum are described in chapter IV. The deposit seems to have been originally anhydrite, part of which has altered to gypsum. In turn the anhydrite was probably derived from limestone by the action of sulphurous waters.

CHAPTER VI

HISTORY OF THE GYPSUM INDUSTRY

The use of gypsum in the arts is recorded in the earliest monuments of civilization. Its value was known to the pyramid builders of Egypt and to artists who wrought during the Egypt eighteenth (1580-1350 B. C.) and later dynasties. Hy-

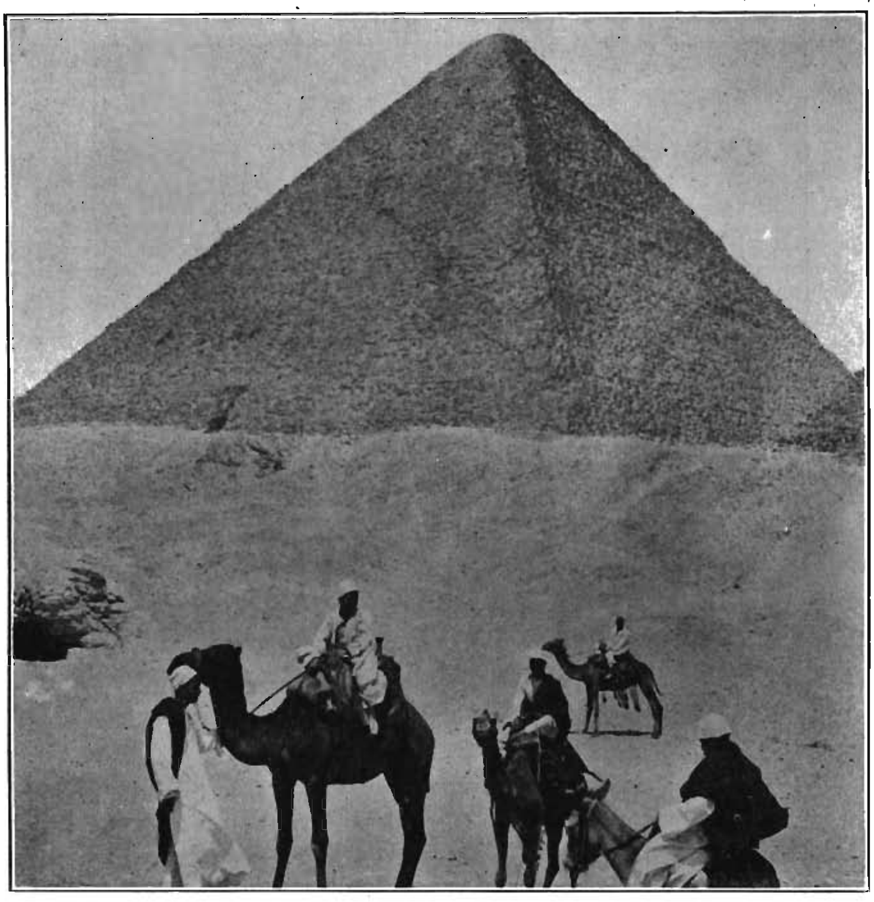


FIG. 15.—Pyramid of Cheops. Hydraulic Gypsum was found in certain portions of this structure and has endured to this time. Copyrighted by and republished through courtesy of Keystone View Co.

draulic gypsum mortar was used in the Pyramid of Cheops* (see chapter XIX) and this mortar is hard and its bond with

* Based on statements in das Kleine Gipsbaubuch des Deutschen Gips—vereins and in Pedrotti's Der Gips und seine Vervendung.

the massive blocks of stone is perfect to this day. A view of this pyramid is shown in figure 15.

Hydraulic gypsum is admirably adapted to exterior uses, and its calcination requires no delicate control of temperature. In this fact may be found the reason for the extensive use of hydraulic gypsum far in advance of other forms of gypsum mortar. The use of calcined gypsum (plaster of Paris) however was not unknown to the Egyptians and to the Greeks. At the capital city of Amenophis IV, Achet-aton (now Tell el

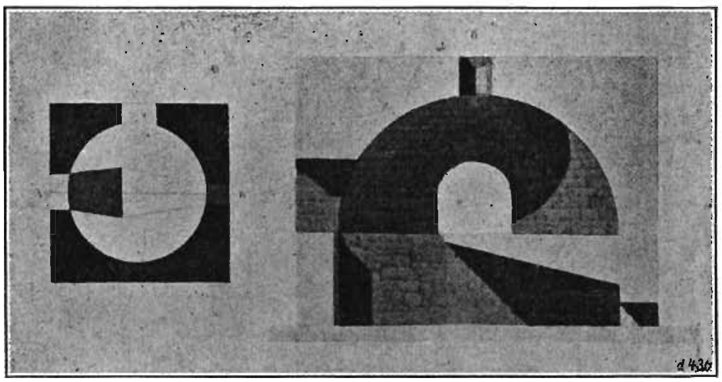


FIG. 16.—Ancient Egyptian calcining oven. From Bericht Deutschen Gipsverein, 1914

Amarna), excavations have brought to light the studio and workshop of Thuthues,[139] who with his associates calcined gypsum, and made plaster of Paris models and masks. Analyses of objects found in this workshop show that they are composed of 57 per cent gypsum and 31 per cent lime.

Theophrastus records that plaster casts were first made by Greece Lysistratus but the Greeks made very little use of gypsum in their art.

The use of hydraulic gypsum was known to the Romans and this material served them well in many important and Rome enduring structures. Alabaster was highly valued by Greeks and Romans and the ancients in general for vases, ornamentation and the lighter forms of statuary. The Romans esteemed gypsum also as a fertilizer.

Hydraulic gypsum formed the mortar used in medieval

139Report of the 14th Assembly of the German Gypsum Association, 1914. An address by Prof. Dr. F. Rattigen, Berlin.

times in the construction of German castles and fortresses. In the vicinity of gypsum quarries, hydraulic gypsum was used exclusively in mortar making. On the southern border of the Hartz, in Thuringia, in Luneberg, Legeburg and elsewhere are found interesting relics[140] of the days of chivalry which are enduring monuments to the worth of gypsum for exterior construction. The beautiful ruins of the monastery at Walkenreed, the ancient cathedral of Bardowiek, the remnants of the walls of Luneburg, Nordhausen and other cities in the Hartz mountains show how gypsum mortar has withstood

Germany

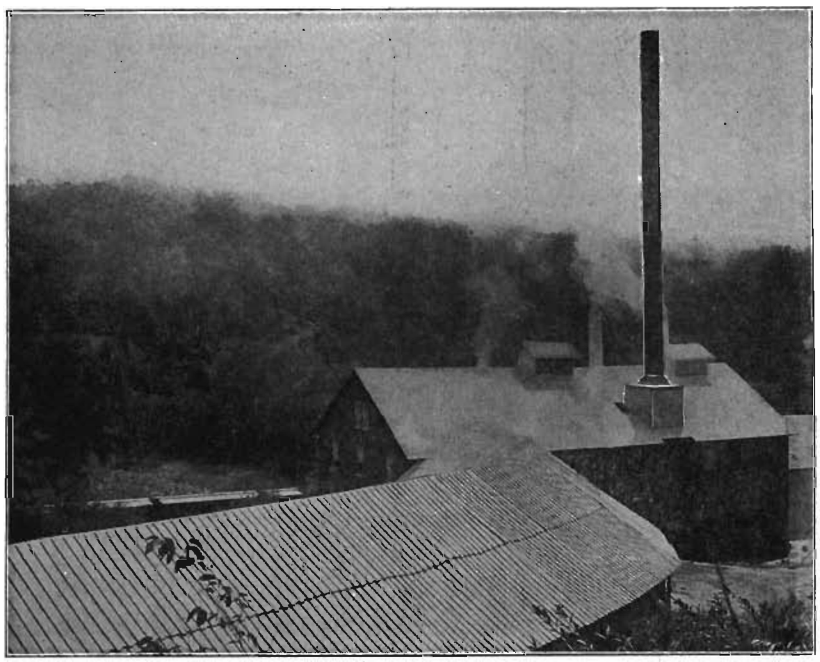


FIG. 17.—Lower mill of Iowa Plaster Association as it appeared in 1902. It has since been completely dismantled.

a trying climate for hundreds of years, and how age has seemed merely to intensify the bond between the gypsum plaster and the stone blocks that compose the ancient structures.

Gypsum was early valued as a fertilizer, and before and after the revolution was extensively used in agriculture. Benjamin Franklin, by word and pen and example urges the use of gypsum on the farm. His famous object lesson, showing the value of gypsum as a fertilizer, is familiar to everyone who has read anything about the life and work of the great

America

140Das Kleine Gipsbaubuch. Published by the German Gypsum Association, Berlin, 1912.

philosopher. He applied ground gypsum to a clover field in the form of large letters with the result that the words "Land Plaster Used Here", could be read for miles in the leaves and greener growth that resulted from the application of the gypsum. Thousands of tons of gypsum, at first imported from Nova Scotia and later quarried in New York state were used annually in the colonies and in the early days of the republic.

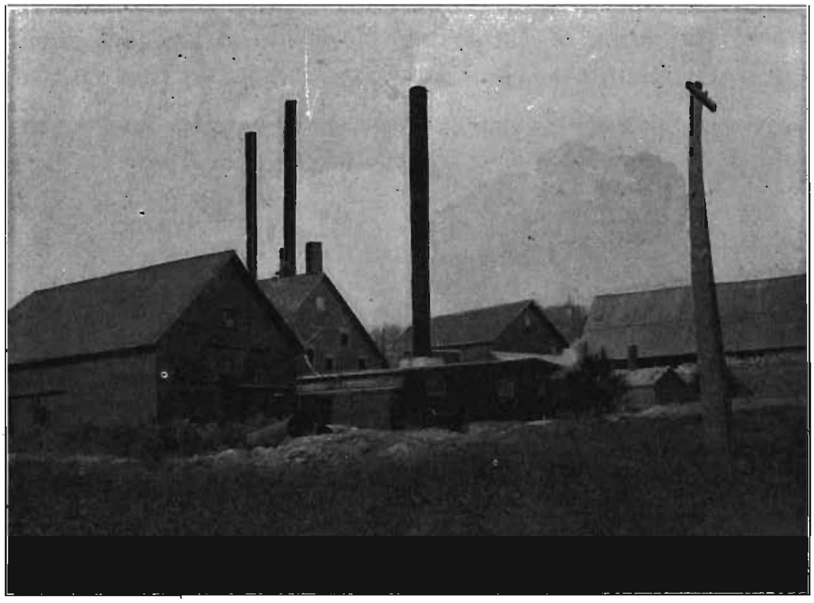


FIG. 18.—The Blandon Gypsum mill, as it appeared in 1902. It was torn down shortly after that date.

As the settlements moved westward, the gypsum deposits of Ohio, Michigan, and Iowa were in turn discovered and developed first for land plaster and subsequently for the manufacture of structural plasters. The development of the land plaster industry is illustrated by the production in the Grand Rapids district of Michigan.[141]

From 1842 to 1850..............................500 tons a year
From 1850 to 1860............................2,000 tons a year
From 1860 to 1864............................3,000 tons a year
From 1864 to 1868............................8,000 tons a year
In 1869..12,000 tons a year
In 1870..12,000 tons a year

141Geol. Survey of Michigan, Vol. IX, p. 47.

There are no figures available for the country as a whole, but as far as is known, the production of land plaster in New York and Ohio was equal to that of Michigan, and considerable quantities were ground in Iowa, while the use of Nova Scotia mineral along the coast, begun in colonial times, was continued and extended. The history of the use of gypsum as a fertilizer is considered somewhat at length in chapter X.

The calcining of gypsum for plastering purposes began in America about 1835 and from a small beginning in New York

FIG. 19.—Mill of the Cardiff Gypsum Plaster Co. as it appeared in 1902. At that time this mill was new. It was the first mill located on the prairie and demonstrated that gypsum mining as well as stripping was practical about Fort Dodge.

state, it gradually developed in every gypsum locality where population was sufficiently dense to offer a market for plastering material.

The primitive gypsum mill consisted of a corn mill and a cauldron kettle. A little later the grinding was done in burr stones, and kettles with an extra heavy cover and capable of holding two or three barrels, were used.

Kettles with two flues were used in New York and from that state the idea was imported into Michigan in 1871 by Freeman Godfrey, one of the pioneers in the gypsum industry in that state.

Calcining introduced

The same years that witnessed the introduction of calcined

FIG. 20.—Mill of the Plymouth Gypsum Co. near Fort Dodge. Courtesy of Plymouth Gypsum Co.

gypsum for plastering purposes, saw the beginning of the decline in its use in agriculture.

Other fertilizers displace gypsum

The reasons for this decline are threefold. First, the rapid growth in the demand for calcined plasters absorbed the attention of the gypsum producers and they made no study whatever of the underlying scientific principles that make gypsum valuable on the farm. Second, competition from potash, nitrate and phosphate fertilizers arose, and agricultural experts recognized the merits of these new fertilizers. Third, land plaster had produced wonderful results but on land where it had been used continuously for years in time it failed to give results of earlier years. The new fertilizers on the other hand on these lands proved very helpful. Chemical analyses of plants, seeds, fruits, and stems, as made at this time aided in obscuring the issue. They showed the reasons why the potash and phosphate were valuable, by demonstrating their presence in the plant tissue, but the high percentage of sulphur present in many plants was volatilized and hence never recorded. So the idea

Reasons for decline of land plaster

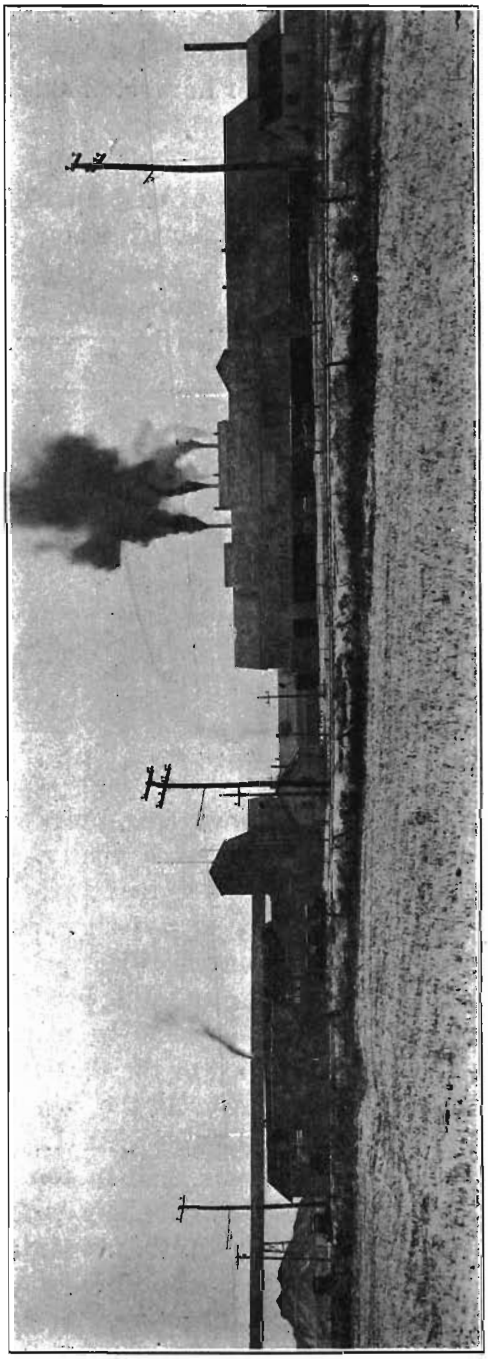


Fig. 21.—Mill of the American Cement Plaster Co., Fort Dodge. Courtesy of the Beaver Board Co.

arose that gypsum was merely a stimulant and furnished no plant food. A stimulant was a bad thing on general principles and all forms of lime were so regarded for a considerable period. The saying that "lime makes the parent rich and the child poor" is quite universally accepted as true.

Revival of land plaster

The revolution in favor of lime compounds began with lime carbonates primarily because they were soil sweeteners, though gradually the recognition of calcium as a plant food was extended.

The use of gypsum as a fertilizer survived in a few localities simply because experience showed that nothing else took its place. The crop that particularly held for land plaster a place in agriculture was the peanut. This legume, like all the members of the family, is a heavy consumer of sulphur and when gypsum was not used the kernels did not fill out and the farmer harvested only a crop of empty shells or pops.

In chapter X the recent history of gypsum in agriculture is set out. This modern period may be thought of as beginning with the publishing by the Wisconsin Experiment Station of Bulletin 14, which showed that sulphur is a plant food as essential as phosphorus for many important crops, and that sulphur in the best and cheapest form is supplied by gypsum.

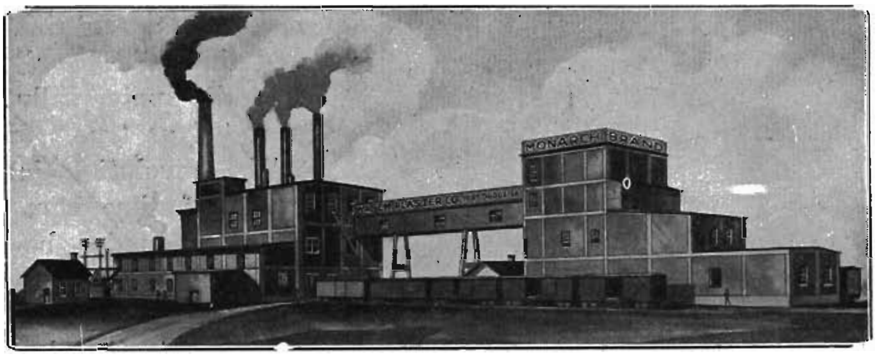


FIG. 22.—Mill of the Wasem Plaster Co. near Fort Dodge. Courtesy of Wasem Plaster Co.

Progress of gypsum plasters

The use of calcined gypsum for interior plastering purposes made rapid and permanent progress. It filled a real need by furnishing a substantial wall surface that favored rapid construction and the freedom of gypsum from dampness was recognized as a great aid to good health.

At first the calcining methods were crude and the product difficult for the plasterer to handle. Improvement in manufacturing processes and greater skill on the part of the plasterer have developed hand in hand. The increase in the use of gypsum plasters is best shown in the table in Chapter XXII.

Gypsum blocks

The writer in 1902, described[142] the processes then in use in Germany for making gypsum blocks. This phase of the gypsum industry had advanced considerably in that country when the first steps toward making blocks were taken in America. Once successfully made and introduced to the

[142] Iowa Geol. Survey, Vol. XII, p. 198-202.

building trade, however, the use of blocks has increased rapidly.

The gypsum board, as that article is understood in American trade, is purely an American product. Of the two types of gypsum board recognized by the trade, namely plaster board and wall board, the plaster board was first developed.

Gypsum board

Plaster board is intended as a base coat, to be covered with one or two coats of plaster. In other words it takes the place of lath and the first coat of plaster. It was first introduced to the trade about fifteen years ago and has met with a favorable reception on the part of architects, underwriters and owners.

Gypsum wall board was perfected about five years ago to meet the demand for a substantial ready made wall, that could

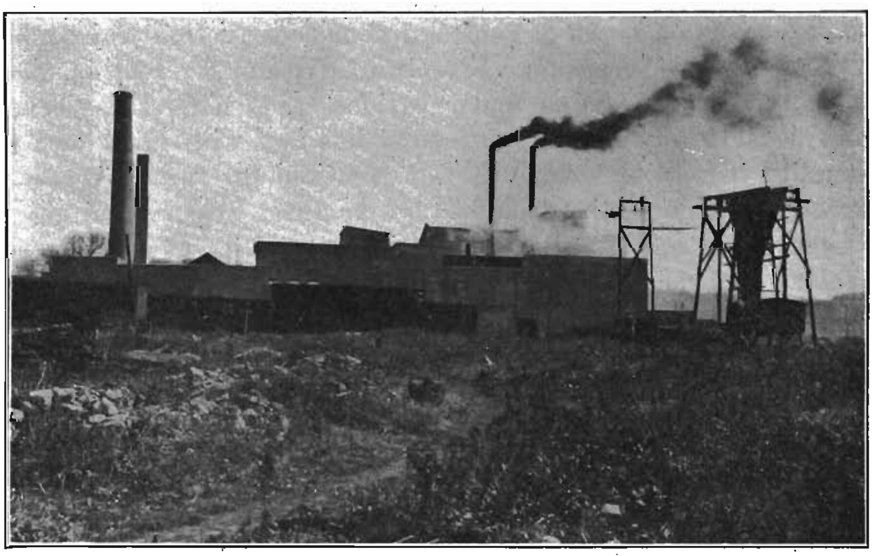


FIG. 23.—Mill of the Iowana Plaster Co. near Fort Dodge. Courtesy of Rock Products.

be put in place by simple methods. The various composition boards had left much that was to be desired. Their fire hazard was great, and expansion and contraction with warping developed unsightly surfaces. The satisfactory showing made by gypsum wall boards on buildings constructed for war purposes in 1917 and 1918 greatly stimulated this phase of the industry.

The properties of gypsum boards, methods used in their manufacture, with specifications and standards are considered at length in Chapter XVII.

Hydraulic gypsum

The German "Estrich"

Gypsum calcined at high temperatures, as has already been noted, was used as mortar by the ancients and was the common mortar used in Europe at points where gypsum was easily won, during the middle ages. The same material is still used extensively for mortar in Europe. It is used also, almost to the exclusion of the Portland cement and lime mixture in vogue in America, for exterior stucco. It is more commonly used for flooring in Germany than Portland cement, and its use for flooring purposes and for exterior stucco is increasing.

Structural gypsum

While the American gypsum industry has not taken advantage of obvious opportunities to enter important fields with hydraulic gypsum it has developed two interesting and important types of roof and floor construction which use calcined gypsum. Structural gypsum for roofing and flooring purposes, going under various trade names, has been on the market about ten years, and has met with favor and a steadily increasing demand. Construction for war purposes greatly stimulated the demand for structural gypsum and gave ample opportunity to demonstrate its flexibility as a building material, as well as its strength, low conductivity and fire resistance.

European and American types of structural gypsum are considered at length in Chapter XVIII.

HISTORY OF THE GYPSUM INDUSTRY IN WEBSTER COUNTY

Mills in Gypsum Hollow

The first gypsum mill in Webster county was erected in 1872 at the head of Two Mile creek, better known as Gypsum Hollow, close to the track of the Illinois Central railroad. The founders of the gypsum plaster industry in Iowa were Captain George Ringland, Mr. Webb Vincent, and Mr. S. T. Meservey. At this time calcined gypsum was used only as plaster of Paris, and for mixing with lime for finish coat in plastering. In 1878 small quantities of gypsum plaster for base coat work were put on the market. Plasterers accustomed to lime mortars only did not quickly comprehend the technique of gypsum plasters, but gradually they became familiar with

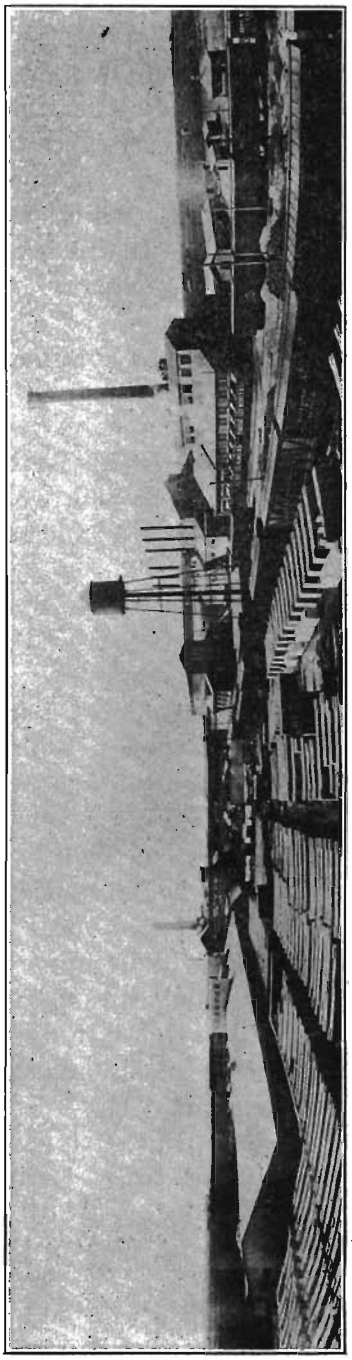


FIG. 24—Mill of the United States Gypsum Co. near Fort Dodge. Gypsum blocks stacked in the foreground. Courtesy of U. S. Gypsum Co.

their manipulation. The growth of the industry progressed steadily as is shown by statistics given in Chapter XXII. In 1882 the second mill was erected, at a point half way down Two Mile creek or "Gypsum Hollow". This mill is shown in figure 17. Three years later the Blandon mill, shown in figure 18, was erected on the river bank below Fort Dodge. The interests controlling these three mills later consolidated and formed the Iowa Plaster Association. The Duncombe was built a little later at the mouth of Two Mile creek and secured most of its gypsum from a quarry on the opposite side of the river. These four mills secured gypsum by stripping at points where the gypsum was exposed along the river and Two Mile creek.

The Blandon mill

In 1899 the Cardiff Gypsum Company sank a shaft through the glacial drift to the gypsum and erected a mill on the open prairie. Figure 19 illustrates this mill. The success of this venture led others to follow the example thus set. In 1900 the Mineral City mill

The Cardiff mill No. 30 on map Mineral City and Crawford mills

was erected, and this was followed soon after by the Crawford mill.

The United States Gypsum Company No. 31 on map

In 1902 the United States Gypsum Company was organized and took over the mills of the Iowa Plaster Association, the Blandon, the Mineral City and the Crawford mills.

The Waterloo mill

Waterloo, Iowa, capital put up the next mill, which was commonly known as the Waterloo mill. It was taken over by the United States Gypsum Company. It burned not long afterward and was not rebuilt.

The Plymouth mill, No. 32 on map

The Plymouth mill was erected about 1905 and has continued to operate as an independent mill.* A view of this mill is given in figure 20.

Iowa Hard Plaster Co. No. 33 on map

The Iowa Hard Plaster Company was organized by Butler and Ryan, and built a mill which was later sold to the American Cement Plaster Company. Figure 21 shows how modern this mill is at the present time.

Acme Cement Plaster Co.

Mr. Ward built the next mill which he soon sold to the Acme Cement Plaster Company. Several years later this mill burned and was not rebuilt.

The Wasem mill No. 34 on map

The Wasem Plaster Company was organized about ten years ago and has been a steady producer since that time. Its first mill was burned in 1918, and another more nearly fire proof structure was erected as promptly as possible on the same site. The present mill is shown in figure 22.

Iowana Company No. 35 on map

In 1920 the mill of the Iowana Company was begun and was completed during the following year. This mill and the Plymouth mill obtain their gypsum from a drift mine on the west side of the river, the rock being transported by overhead tram. A view of the Iowana mill is shown in figure 23. The Iowana mill uses the method of making plastic gypsum which is discussed on page 176 and in Appendix VII.*

The older mills taken over by the United States Gypsum Company were later dismantled and activities were concentrated at the Mineral City plant which was enlarged till it became one of the largest in the United States. A view of this mill is shown in figure 24.

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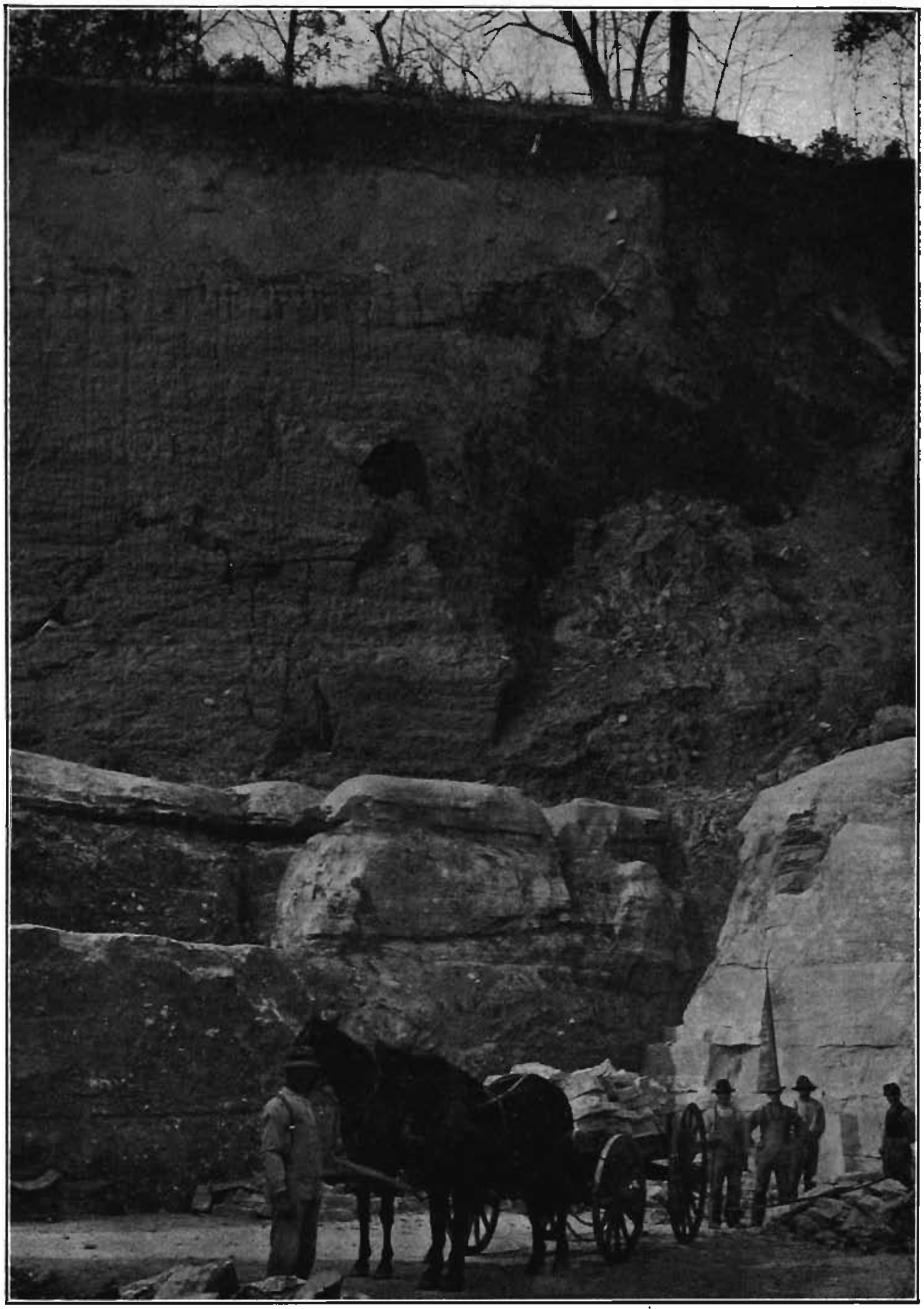
* Since this text was written the Plymouth and Iowana mills have been taken over by the Universal Gyspum Company, a corporation organized for the purpose of operating mills in all the more important gypsum centers.



Quarry that furnished gypsum for the lower mill of the Iowa Plaster Co. in Gypsum Hollow, as it appeared in 1902. The overburden is glacial drift. Note the solution channels and the bedding and jointing, which aid in quarrying and mining.

At present the following companies have each one mill in operation. They are listed in the order in which they began operations in the Fort Dodge field:

Cardiff Gypsum Plaster Company.
United States Gypsum Company.
Plymouth Gypsum Company.*
American Cement Plaster Company.
Wasem Plaster Company.
Iowana Plaster Company.*

HISTORY OF CENTERVILLE GYPSUM FIELD

In 1910 the Scandinavian Coal Company discovered gypsum in the course of prospecting which it undertook near the town of Centerville in Appanoose county. Additional drilling proved the presence of gypsum in the region in commercial quantities and in July, 1912, a shaft was started. This shaft was completed in September of the following year. Considerable quantities of water were encountered in the shaft and no further work was done till 1917. At that time the water was cut off successfully and a two kettle mill was erected, and is now in operation. The mill is illustrated in figure 25.

FIG. 25.—Mill of Centerville Gypsum Co., Centerville, Iowa. Courtesy of Centerville Gypsum Co.

* Taken over by the Universal Gypsum Company in 1922.

CHAPTER VII

PHYSICAL AND CHEMICAL CHARACTERISTICS OF IOWA GYPSUM

THE FORT DODGE BEDS

The Fort Dodge gypsum is distinctly bedded, the layers ranging from two inches to a foot in thickness and separated by traces of clay. The easy parting along bedding Bedding planes is a distinct advantage in mining Fort Dodge gypsum. The nature of this bedding is distinctly shown in Plate VII and in figure 26, which shows a mine interior, and

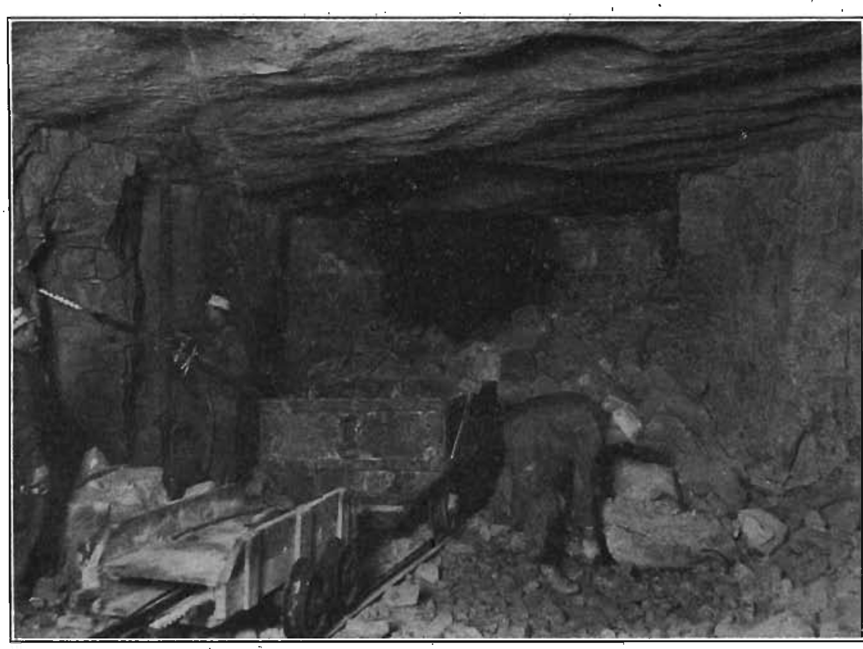


Fig. 26.—Room in the mine of the American Cement Plaster Co. at Fort Dodge. Courtesy of the Beaver Board Co.

also in figure 27, a view of a house in Fort Dodge which was built of gypsum. Several gypsum buildings are still standing in the "Mineral City". The Fort Dodge gypsum bed, taken from top to bottom, has certain well defined characteristics, and as a result the face of the quarry or mine is divided "Ledges" into "ledges" by the miner. The group of layers making a "ledge" may be recognized in mines separated by

FIG. 27.—A house in Fort Dodge, built of gypsum. Photo by Lees.

a considerable distance. The following subdivisions are commonly recognized in the Fort Dodge area.

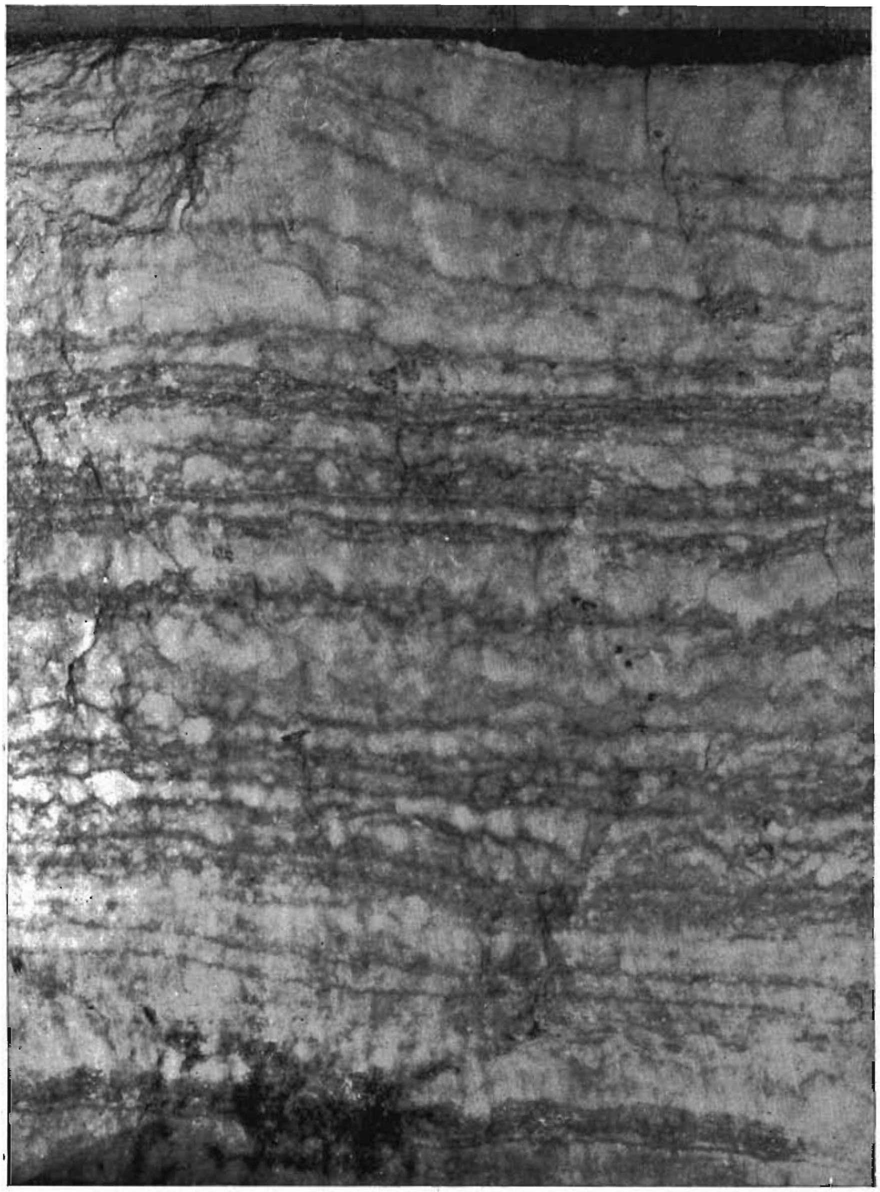
		Feet
5.	Upper rock, varying in thickness on account of differences in loss due to erosion and solution	3–12
4.	Six foot ledge	6
3.	Hard ledge	4
2.	Eighteen inch ledge	1½
1.	Bottom ledge	5

Lamination lines are suggested by streaks with a green-gray tinge which parallel the bedding. These alternate with white Lamination lines. The structure is shown in Plate VIII. The material in each one of these bands seems to have crystallized at one time and each band represents a period of some sort. Their average thickness is about one-third of an inch and if they represent annual deposits, the interval required to deposit the gypsum can be simply and quite accurately determined. A foot of gypsum would represent thirty-six to forty years and assuming thirty feet for the original thickness of the beds, 1200 years would suffice for their accumulation. It is quite probable that rapid deposition took place during the hot dry summer period, when the mineral in solution was concentrated due to evaporation and to limited flow into the basin. During the winter, with conditions reversed, crystallization doubtless stopped, and the water became slightly clouded with earthy matter so that the first deposit of the summer was slightly gray in color.

Many observers have wondered at a peculiar phenomenon in connection with the top layer of the gypsum exposures where the mineral has been stripped and subjected to heat and rain for some time. Such conditions occur at a number of points along Two Mile creek, better known as Gypsum Hollow. Some of the upper layers of gypsum have been arched up till small circular or elliptical domes are formed. The walls of these domes are six or seven inches in thickness. See figure 28 for an illustration of this phenomenon.

Expansion peculiarities

FIG. 28.—A dome in Fort Dodge gypsum. The top of the dome, which appears in the foreground, has been broken. Photo by Lees.



Fort Dodge gypsum showing its banded structure.

As the Fort Dodge gypsum contains no anhydrite it is not possible to explain the expansion by assuming that the mineral has taken on additional water. The explanation probably lies in the fact that the gypsum is slightly pervious and hence mineral dissolved in rain water is carried into the body of the rock and crystallizes out around already existing crystals, increasing their size, with the resultant expansion and doming of the layers.

Cause of domes

The conditions for these processes have been particularly favorable since the old quarries were stripped and then abandoned, but might have taken place at any time in the past when the gypsum was not protected by overlying impervious beds.

Lees has photographed and described the exceedingly irregular solution surface of the gypsum which may be seen from time to time in the Vincent clay pit, as follows (see also figure 29):

Solution surfaces

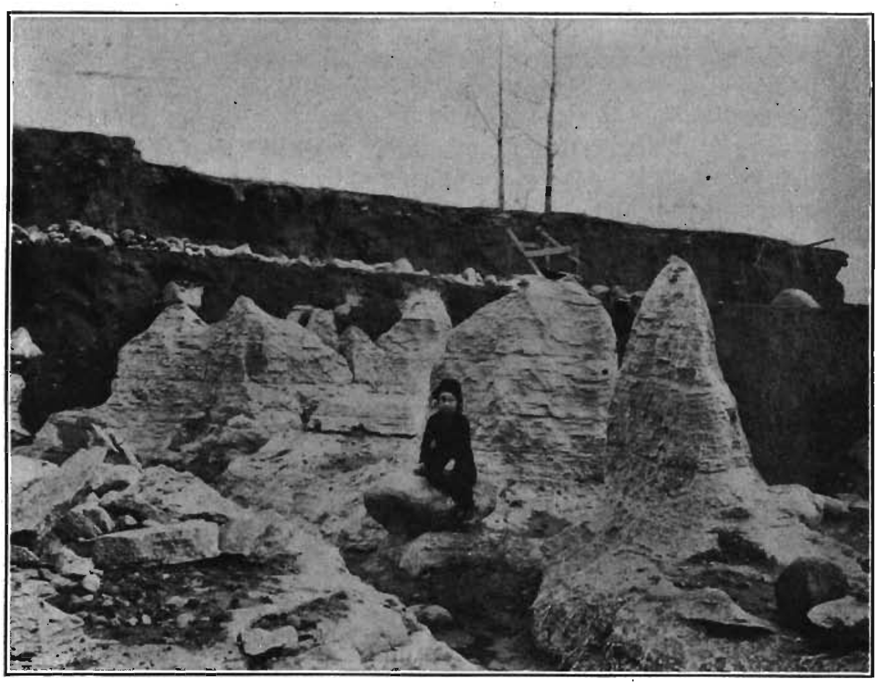


FIG. 29.—Pinnacles, resulting from solution of gypsum; exposed by hydraulic stripping, Vincent Clay pit, Photo by Lees.

"The overburden of drift at the Vincent clay pit is removed by hydraulicking. The gypsum, which here has a maximum thickness of about seven feet, is then broken up and removed. In the fall of 1917, quite a large area had been cleared of drift and a remarkably irregular surface of the gypsum was revealed. From its nature it is evident that the irregularity was caused by aqueous solution or erosion rather than by ice erosion. Sinuous winding channels have been cut almost through the gypsum bed as the accompanying views show. What was apparently a larger channel extended almost the entire length of the stripping. Pinnacles and towers and walls of fantastic design have been carved in the solid rock and a most picturesque miniature topography has been formed. Potholes or pothole-like cavities have been dissolved out where we may imagine that the tiny torrents dashed and swirled or the slowly percolating waters of a bygone day seeped among the rocks and clays that formed the surface of that time.

"There is little evidence to show the age of this solution surface. In some places gray drift fills the hollows in the gypsum while yellow oxidized till extends across hollows and eminences alike, without curving down at any point. In one place an oxidized band bends up over the gypsum mound. There is no indication of slumping or settling of drift into the hollows as the gypsum was dissolved away. If all of the drift here is Wisconsin, as it seems to be, its condition and position would seem to indicate that the solution was accomplished mostly in pre-Wisconsin (Peorian) time at least, and it might, of course, be earlier than that. The illustrations show that the pebble band and the humus zone extend, for the most part, in uniformly straight lines parallel with the surface of the ground. The fact that this locality is on the upper slope of the valley wall makes escape of the ground water easy and would permit of relatively rapid passage of these waters through and over the rock. This condition might point to a more recent date for the formation of this surface. At the same time similar topographic conditions have prevailed since the valley was formed in post-Kansan (Yarmouth) time so that similar opportunities for solution have been offered for a long period of time."

The ice could never have overridden these soft and tender pinnacles without obliterating them. As the material filling the crevices is normal drift it cannot be said that outwash material filled the irregularities, and that the ice subsequently rode over the gypsum pinnacles which were packed, as it were, and protected from breakage. There seems to be only one explanation, and that is solution in post-Wisconsin time. The Wisconsin ice probably removed the overlying shale that protected the gypsum from solution, and may have scoured away more or less of the gypsum. The oxidation of the yellow till which Lees speaks of as often extending over hollows and eminences in the gypsum alike, must be subsequent to the formation of these solution phenomena. The pebble bands and humus zone also, which run for the most part in uniform straight lines parallel with the surface of the ground, are developments more recent than the solution channels, but may easily have been developed within very recent times.

The Fort Dodge gypsum is remarkably pure calcium sulphate with water of crystallization ($CaSO_4\ 2H_2O$). At the base of the gypsum there are six inches of quite impure mineral. The rest of the bed is quite uniform and of a consistently high quality. The earlier analyses by Patrick made a distinction between the upper part of the bed and the lower five feet. These analyses indicated for the upper part of the bed, a mineral almost chemically pure.

Chemical composition

The analyses of the lower part of the bed, while showing that it was inferior to the upper part, nevertheless showed it to be purer than most of the commercial gypsum of the country. They are given below.

Earlier analyses

	Upper Layer[143]	Lower Layer[144]
Calcium sulphate	78.44	76.28
Water of crystallization, calculated	20.76	20.72
Insoluble matter	.65	2.92
	99.85	99.92

The absence of calcium carbonate in these analyses as well as in analyses made by other investigators in various fields, raised the question as to whether gypsum could be deposited from sea water, without some measurable amount of calcium carbonate being deposited with it. A negative conclusion was reached by Stieglitz, whose work in this connection is briefly reviewed in Chapter III.

Analyses of Fort Dodge gypsum made for this report at

143Analysis by G. E. Patrick, Iowa Geol. Survey, Vol. II, p. 291.
144Analysis by J. B. Weems, Iowa Geol. Survey, Vol. XII, p. 110.

the chemical laboratories of the State University of Iowa, and given below, show easily measurable quantities of calcium carbonate (limestone) and it is quite probable that in other cases a thorough search for the carbonate will result in its discovery.

Recent analyses

STATE UNIVERSITY OF IOWA
DEPARTMENT OF CHEMISTRY
ANALYSES OF GYPSUM FROM FORT DODGE[145]

(I) *PLYMOUTH GYPSUM COMPANY*

	PER CENT	CALCULATIONS	PER CENT
Calcium oxide	31.24	Gypsum	92.91
Sulphur trioxide	43.21	Limestone	1.77
Water	19.42	Silica	2.23
Iron and alumina	3.25	Iron and alumina	3.25
Silica	2.23		
Carbon dioxide	.78		100.16
	100.13	Calcium sulphate, anhydrous	73.47

(II) *AMERICAN CEMENT PLASTER COMPANY*

	PER CENT	CALCULATIONS	PER CENT
Calcium oxide	31.90		
Sulphur trioxide	44.95	Gypsum	96.65
Water	20.06	Limestone	0.70
Iron and alumina	1.55	Silica	1.28
Silica	1.28	Iron and alumina	1.55
Carbon dioxide	.31		
			100.18
	100.05	Calcium sulphate, anhydrous	76.43

Another sample collected near Fort Dodge by Doctor Lees and analyzed by Marquis and Jennings gave:

	ANALYSIS "A" PER CENT	ANALYSIS "B" PER CENT	ANALYST
SiO_2	1.81	1.70	Marquis
Al_2O_3 / Fe_2O_3	.85	.90	Marquis
CO_2	.55	.59	Jennings
CaO	32.42	32.14	Jennings
MgO	--------	--------	
Total H_2O	19.94	20.04	Jennings
SO_3	44.73	44.77	Jennings
	100.30	100.14	

145Samples collected by Doctor Lees from the working faces of the mine, in such manner as to secure an average sample for the working face.

THE CENTERVILLE GYPSUM

PHYSICAL PROPERTIES

Color and partings

The Centerville gypsum is white, free from the colored bandings so characteristic at Fort Dodge, and lacks partings and bedding planes.

Texture

In texture it varies from coarse crystalline to fine granular. Portions of it are saccharoidal and distinctly friable.

Associations

It is, in places, closely associated with anhydrite and the appearance of the mass in such cases is somewhat mottled, due to the light blue color of the anhydrite which is surrounded by the whiter gypsum. Considerable bodies of the gypsum will doubtless be found that are entirely free from anhydrite, and it is quite likely that it will prove practical on a commercial scale to separate the gypsum from the anhydrite, and to use each grade of mineral for purposes for which it is adapted. A view of the mine face is shown in figure 30.

FIG. 30.—A view in the mine of the Centerville Gypsum Co. Courtesy of Centerville Gypsum Co.

CHEMICAL COMPOSITION

With the exception of a few inches near the bottom of the bed the Centerville gypsum, where free from anhydrite, is remarkably pure. The following analyses are by Jennings:

	Analysis 1 Per cent	Analysis 2 Per cent
CO_2	.76	.79
SO_3	45.92	45.80
Al_2O_3 } Fe_2O_3 }	.28	.26
CaO	32.11	32.42
MgO	.18	.17
Total H_2O	20.06	20.02
	99.31	99.46

Analyses[146] of a sample which from the variation in its hardness and color was easily recognized as a mixture of gypsum and anhydrite gave the following:

	Analysis 1 Per cent	Analysis 2 Per cent
CO_2	1.76	1.69
SO_3	52.60	52.54
SiO_2	traces	traces
Al_2O_3 } Fe_2O_3 }	.62	.61
CaO	36.32	36.70
MgO	2.09	2.12
Total H_2O	5.61	5.58

A sample which had the typical glassy luster of pure anhydrite, as well as the fine grain and light blue color, nevertheless on chemical analysis was found to contain over 3 per cent of water of crystallization. Probably small quantities of gypsum will be found in all of the Centerville anhydrite.

Analyses made under the direction of Prof. S. W. Beyer of the Iowa State College gave the following results[147]:

	Gypsum		Anhydrite		
	1	2	1	2	3
Sulphur trioxide (SO_3)	46.56	45.65	54.12	55.29	54.45
Lime (CaO)	33.37	32.76	40.20	40.67	39.58
Loss on ignition	20.03	20.75	6.62	4.66	5.13
	99.96	99.16	100.94	100.62	98.16

An interesting development at Centerville was the discovery

Caves of a cave in the gypsum. This opening, which is, of course, an old water channel, is twenty feet wide, fifty feet long and seven feet high.

It was, when found, lined with beautiful crystals of selenite, some of them of unusual size. These are well illustrated by Plate II, p. 69.

146By Jennings.

147U. S. Geol. Survey Bull. 580-E, p. 64. Also Iowa Geol. Survey, Ann. Rept., Vol. XXI, p. 24.

CHAPTER VIII

TECHNOLOGY OF GYPSUM AND GYPSUM PLASTERS

Winning of gypsite

The loose, granular, and somewhat impure form of gypsum known as gypsite, commonly lies on or near the surface and is placed in the mill by simple methods. The material may be excavated with shovels, either hand or steam, or with wheel scrapers. No explosives are necessary, and as a rule deposits that require much stripping are not worked. The gypsite is loaded directly into cars, carts or wagons, which are dumped into proper mechanical appliances for delivering it to the kettle bins or to a dryer.

Quarrying gypsum

A considerable percentage of the gypsum of commerce is taken from quarries. Twenty years ago very little gypsum was mined, as there were ample exposures, generally along rivers and creeks, with a relatively small amount of overburden. This was true in the Grand Rapids and Fort Dodge fields, and is still true in the Alabaster, Michigan, field and at many points in the west. As the work progressed, however, and the quarry faces receded into the upland, the stripping became more and more arduous, and quarrying gave place to mining.

Drilling, hand

Drilling in quarries may be carried on by hand and by steam, compressed air, and electricity. The softness of the mineral favors hand drilling, and up to ten years ago this was the method commonly employed. After stripping, churn drill holes were sunk to a depth in keeping with the face of the quarry and the breaking properties of the gypsum, and these holes, after being loaded, were discharged by fuse or battery.

Drilling, steam and air

Any of the numerous machines designed for drilling vertical holes may be used in a gypsum quarry. At least twice the footage per hour may be obtained in gypsum that is secured in limestone with the same equipment.

Explosives

Both dynamite and black powder are used in quarrying and mining gypsum. When dynamite is used, a low nitro is preferred for the conditions that generally prevail.

For underground work the room and pillar method is generally employed. This system is used in the Iowa fields, at Grand Rapids, Michigan, Oakfield, New York, and in general at all points where the beds are of moderate thickness and pitch. In the Virginia field stoping methods are employed. Figure 31 shows a typical room in a Fort Dodge mine. The pronounced bedding and jointing of the Fort Dodge

Mining methods

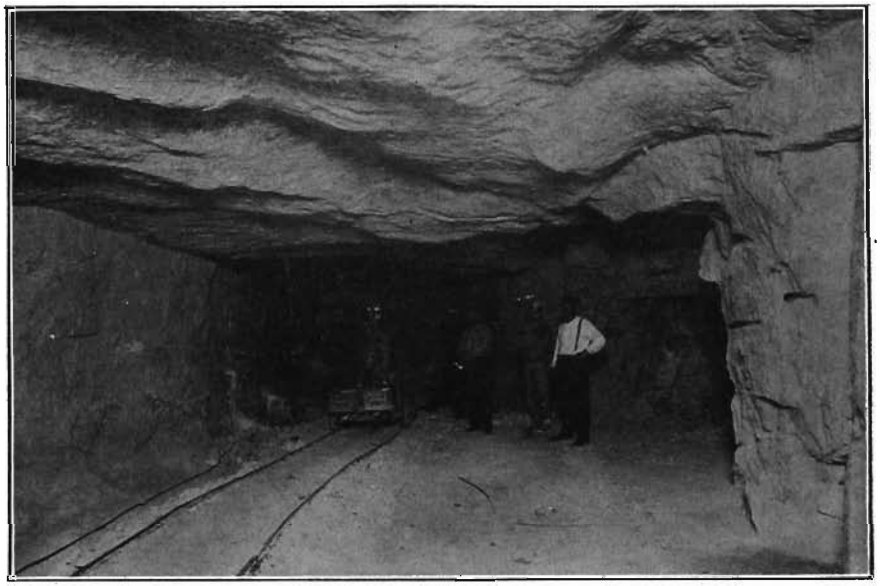


FIG. 31.—A portion of the mine of the Plymouth Gypsum Co. Courtesy of Plymouth Gypsum Co.

gypsum greatly aids in the breaking of the mineral, and the amount of mineral won per unit of explosive compares favorably with that of any mining field in the country. In the Oakfield, New York, district the gypsum is keyed in by irregularities in roof and floor and breaking is somewhat difficult in consequence. The texture of the rock differs in different mines, and in some cases differs in different rooms in the same mine. The amount and kind of explosive that give the best results will depend in some measure on the texture of the mineral.

Gypsum generally makes a good mine roof. Its crushing strength is fairly high, as has been shown in Chapter I, and the proper relationship between room and pillars may be easily determined by estimating the overburden. If the surface is not too valuable, it is customary to rob the roof and pillars after the manner common in coal mines.

The great solubility of gypsum renders mud seams and water courses even more common than in limestone and in the Fort Dodge field these mud seams present the only unfavorable mining feature.

The amount of water encountered in the Fort Dodge mines is moderate. In the shaft of the Centerville mine a considerable flow was encountered when the shaft was sunk, coming from the limestone that lies just above the gypsum. This was successfully cut off, however, and no serious trouble from water has since been encountered.

The gypsum after coming from the mine passes directly to the crusher. In some mills it goes through "grizzlies" on the way to the crusher. These consist of a series of bars which

Crushing

permit the finer material that does not need crushing to fall through. The fines pass directly by spiral or belt conveyor to bins for pulverizing. The lump going over the grizzly falls into the crusher which is usually either a jaw crusher, a gyratory or a large cone crusher. In one mill large rolls of the Edison type are used, and are reported as operating successfully. A common type of crusher is shown in figure 32.

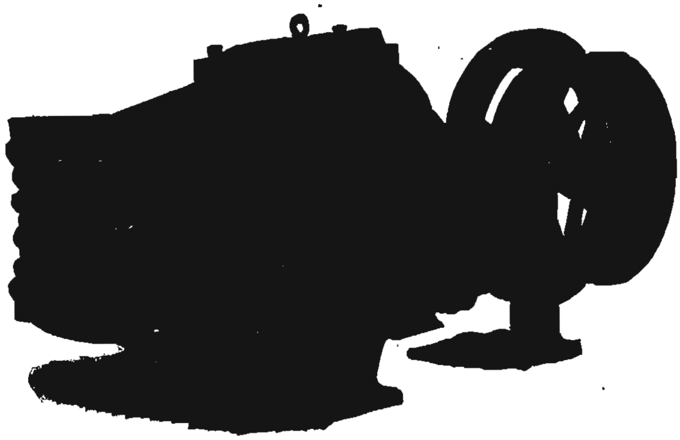


FIG. 32.—Jaw crusher of the type often used in gypsum mills. Courtesy of the Ehrsam Mfg. Co.

The criticism usually passed on both gyratories and rolls in connection with the crushing of gypsum grows out of the tendency of the mineral to "gum up", that is, to adhere to the metal at the points where the pressure is applied. If the gyratory or the rolls are sufficiently large, however, this criticism has no great weight.

As a rule only one coarse crusher is installed and this machine has capacity to meet the output demanded of the

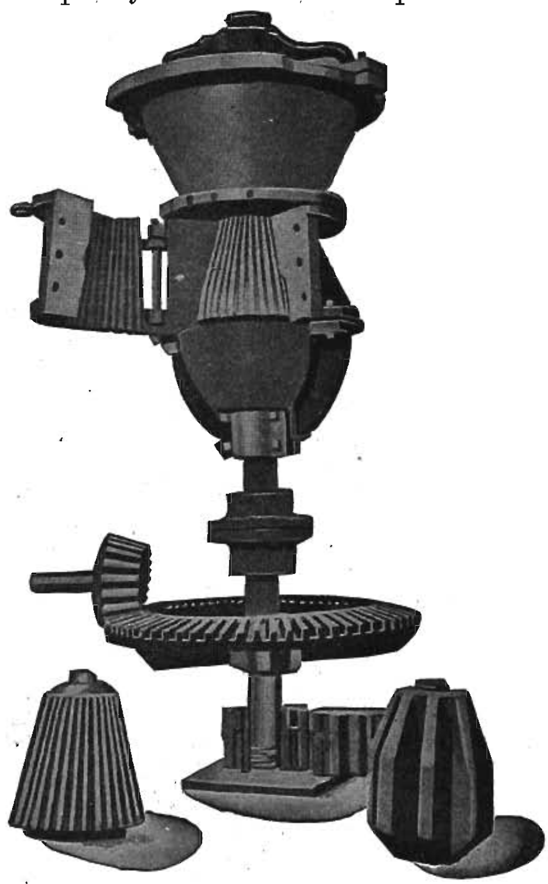


FIG. 33.—Cone crusher or cracker which is commonly used in gypsum mills to further reduce the product coming from the jaw crusher. Courtesy of New York Geological Survey.

mill. Some crushers have a capacity of fifty or more tons an hour while in the smaller mills a machine that will reduce twenty tons in an hour is ample. From the coarse crusher it is a common and a desirable practice to pass the material over or through magnetized surfaces, to take out iron in the form of mine spikes, wedges and other mining tools, which are often shoveled into the mine cars with the finer gypsum and make serious trouble if they reach the "nipper" or "cracker," as the fine crusher is called. In a few mills where very large gyratory, or cone crushers are used, the crushing is completed in a single operation.

The fine crusher is in the essentials of its construction like an immense coffee mill. Its capacity is usually equal to that of the coarse crusher whose operation it follows. Within a corrugated shell made in the form of two funnels, the lower one inverted and bolted to the upper, are two corrugated cones, the upper one coarse, and the lower one reversed in position with fine corrugations to match those on the sides of the inverted funnel-like shell within which it revolves. The nipper, or cracker, as the crusher is called, may be driven from above or below by bevel gear. There are a number of advantages in the upper drive, the main one being the fact that the gears are out of the way of the dust that commonly leaks through the nipper, at times in considerable quantities. Figure 33 shows a common form of cracker. The gypsum on leaving the cracker is of walnut size or smaller. The material fed to the cracker from the crusher varies in size with the size of the installation, the large jaw crushers allowing fragments six or eight inches in diameter to fall through. These are easily crushed in the nipper, which must, of course, correspond in size with the crusher.

In many mills it is customary to pass the gypsum through a dryer before attempting to pulverize it. The need of a dryer depends largely on the amount of pore filling or hygroscopic water that is present in the gypsum. If the mineral contains
Drying much free moisture the cost of fine grinding is greatly increased on account of the large amount of power required and the reduction in the capacity of the machine. Most of the heat given to the gypsum in the dryer is retained till the mineral reaches the kettles and shortens the time required for calcining. The contraction of the kettle bottom is reduced also by charging it with warm dry material. Several dryers on the market are suitable for use with gypsum which does not present any special peculiarities in connection with the drying problem

except that of the dust. Gypsum dust from the dryer represents a considerable waste if it is not saved.

For fine grinding a variety of methods are used. In some plants gypsum from the nipper or dryer passes directly to burr mills. The burrs may be of American or imported stone. Grinding on burr mills produces rounded particles, which is desirable as compared with angular fragments produced by certain types of disintegrators. The low first cost of the burr mill is in its favor, but its upkeep is expensive as the stones must be dressed often by skilled workmen if a uniformly

Grinding, burr mills

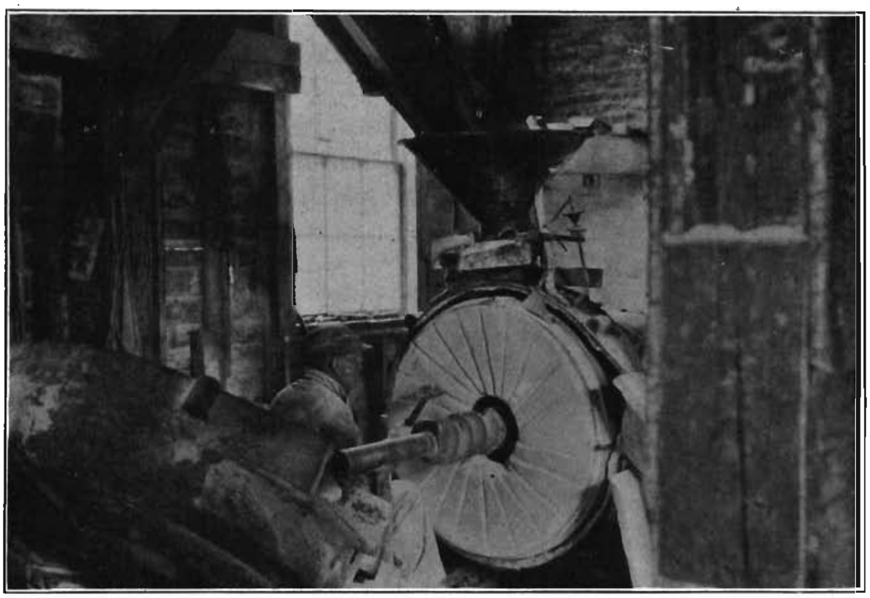


FIG. 34.—Burr mill of the type commonly used in Iowa plaster mills for fine grinding. Courtesy Centerville Gypsum Co.

fine product is secured. Their power consumption is high if very fine grinding is required. Figure 34 shows one of the burr mills in the plant of the Centerville Gypsum Company.

A modification of the burr mill is found in the vertical and horizontal emery mills which are used to some extent in pulverizing gypsum. In these mills blocks of emery are skillfully set in a cement matrix, and on account of the superior hardness of the emery these mills require less

Horizontal emery mill

attention than those using burr stones. A sectional view of one of these emery mills is shown in figure 35.

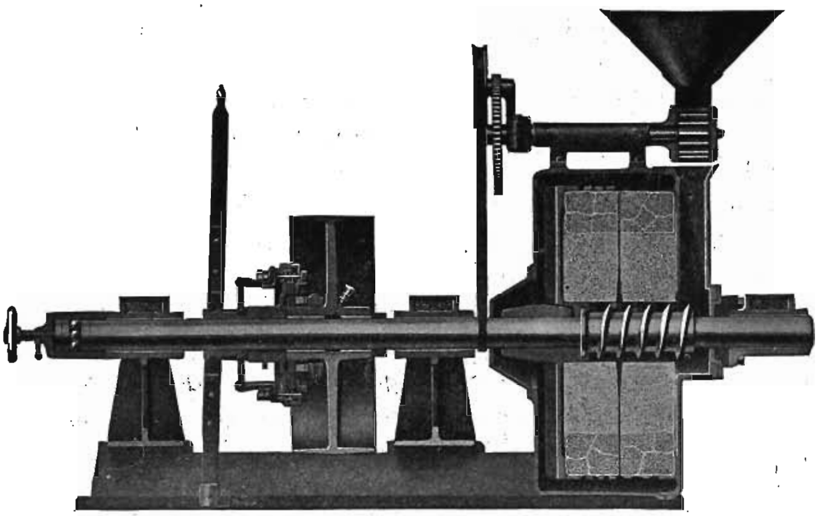


FIG. 35.—Vertical emery mill. Often used for fine grinding of calcined gypsum. Courtesy New York Geological Survey.

For some years disintegrators of various makes were used

FIG. 36.—A hammer mill. Several mills of this type are on the market and they are sometimes used in gypsum mills for initial crushing and grinding. Courtesy New New York Geological Survey.

with a fair degree of success. Machines of this type reduce the gypsum to a fine powder by means of rapidly revolving hammers, striking by centrifugal force. A cross section of one of these machines is shown in figure 36. The fragments produced by the disintegrator seem to be angular, and do not give the same good working qualities to the plaster that are secured by the rounded particles turned out by the old burr mills. The capacity of the disintegrator, however, is very large, the first cost is not excessive and the power required per ton of finished product is low.

Disintegrators

Because they desire to take advantage of the good features of the disintegrator and at the same time to secure a finer product than it can deliver and one containing rounded instead of angular particles, some plaster producers pass the product of the disintegrator over screens, sending the material that passes through the screen to the kettle bins for calcination and returning the tailings to burr or emery mills for grinding.

Screens are used also where all of the grinding is done on burr or emery mills, to secure a finer product, and in this case the tailings are either returned to the mill doing the primary grinding or pass on to other burrs which grind finer than the first. Rotary screens have not proven wholly satisfactory for this purpose on account of the tendency of the gypsum to clog the perforations, and vibratory screens of some type are generally preferred.

Screens

The chart shown as Plate IX gives a typical flow sheet for a gypsum mill.

During the past five years roller mills have found great favor with many gypsum producers, because certain types, at least, of these machines yield a large amount of very fine material in a single operation. They are particularly advantageous if the gypsum contains any hard impurity which injures the faces of the stones in burr and emery mills. On this account, for example, roller mills of various types have found special favor in the Ohio field where in some portions of the gypsum beds chert in limited quantities is present.

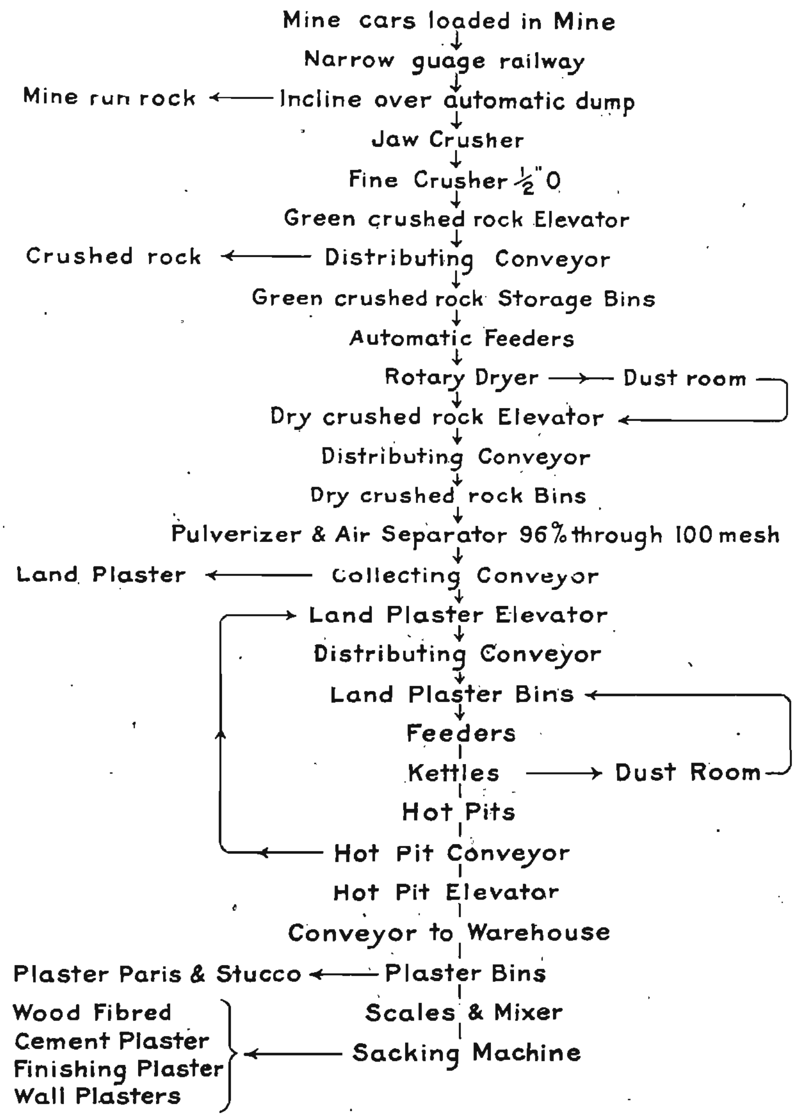
Roller mills

The principle in most roller mills used for grinding gypsum involves roll crushing in one way or another, with air separation. There are on the market roller mills from which the fines are taken by screens, but they are not generally acceptable for gypsum because the spaces clog too easily, whereas with air separation the large fan carries the fines readily to the collecting chambers where simple adjustments permit the operator to return to the mill for regrinding any portion that is below the standard of fineness that he has adopted.

The horsepower required for roller mill grinding in standard machines is one horse power per ton of gypsum ground each twenty-four hours, the gypsum being reduced so that 90 per cent will pass a hundred mesh screen.

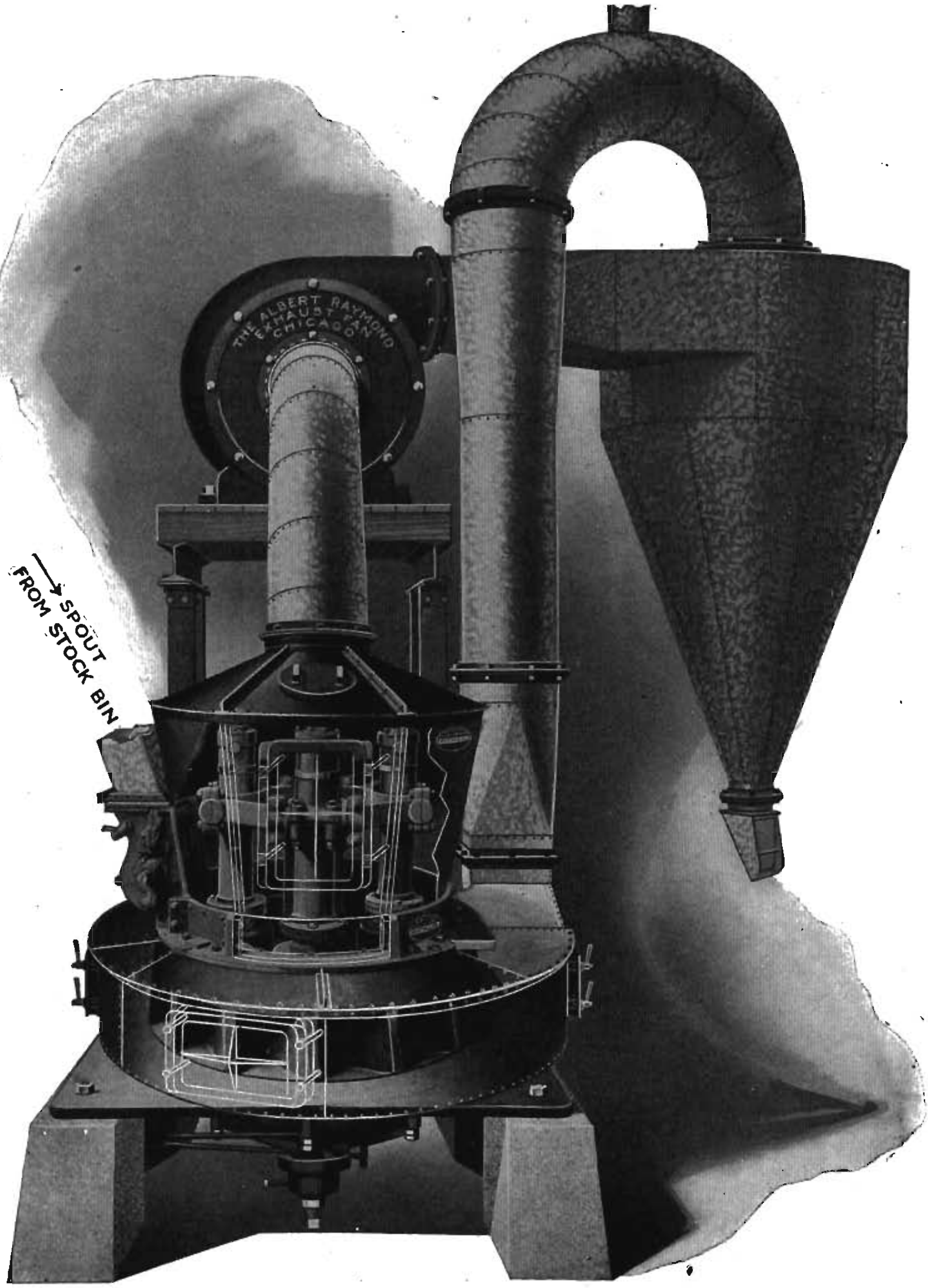
Plate X shows a type of roller mill in common use for grinding gypsum. Four or five heavy rolls are suspended from a central shaft and when this shaft is rotated the rolls by centrifugal force press against a broad steel ring. The gypsum is mechanically fed to the machine and by properly arranged blades or scrapers is kept crowded against the steel ring on which the rolls press while rotating. A strong air current produced by a large fan carries away the fines to a collector where the coarser particles are separated and are returned to the mill for regrinding, while the gypsum of approved fineness passes on to the kettle bins.

The tendency in the gypsum industry during the past fifteen years has been toward finer grinding. This has been in response to the demand of contractors for a plaster that would **Fineness** carry more sand and on the part of plasterers for plaster that could be applied with the least effort. During the summer of 1918 and the fall of 1921 Fort Dodge plasters were secured on the market and tested for fineness by the Department of Engineering at Iowa State University. In the determination of fineness Tyler standard screen scales, shaken by a Tyler Ro-Tap Sieve Shaker, were used. The report on the 1918 tests follows.



Notes: Crusher capacity 30 Tons per Hour
Dryer " 40 " " "
Elevating & Conveying Machinery 45 Tons per Hour
Calcining capacity finished Mill 20 " " "
Loading capacity:
Crushed rock 30 Tons per Hour
Unfibred Goods 30 " " "
Fibred Goods 22 " " "

Flow sheet of a typical gypsum mill. Courtesy of Department of Mines, Canada.



A roller mill with air separator of the type used in many gypsum mills for fine grinding. Courtesy of Raymond Bros. Impact Pulverizer Co.

SIEVE ANALYSIS

Screen No.	Size of Mesh in inches	N Per cent Retained	N Per cent Passing	O Per cent Retained	O Per cent Passing	P Per cent Retained	P Per cent Passing
14	.046	0.0	100.0	0.0	100.0	0.0	100.0
20	.0328	1.0	99.0	0.0	100.0	0.0	100.0
48	.0116	7.5	92.5	1.5	98.5	5.5	94.5
65	.0082	13.0	87.0	6.0	94.0	10.5	89.5
100	.0058	24.0	76.0	20.5	79.5	23.5	76.5
150	.0041	40.0	60.0	34.0	66.0	40.5	59.5
200	.0029	51.0	49.0	50.0	50.0	51.5	48.5

Q Per cent Retained	Q Per cent Passing	R Per cent Retained	R Per cent Passing	S Per cent Retained	S Per cent Passing	T Per cent Retained	T Per cent Passing
0.0	100.0	0.0	100.0	0.0	100.0	0.0	100.0
0.5	99.5	0.0	100.0	0.0	100.0	0.0	100.0
5.0	95.0	6.0	94.0	5.0	95.0	14.0	86.0
10.5	89.5	11.0	89.0	10.0	90.0	21.5	78.5
27.0	73.0	31.5	68.5	25.0	75.0	33.0	67.0
50.5	49.5	51.0	49.0	39.5	60.5	44.5	55.5
65.0	35.0	60.5	39.5	48.5	51.5	55.5	44.5

The plasters used in the tests just described were all wall plasters, as distinguished from plaster of Paris and finishing plasters, and they are more fully described below:

Laboratory Designation	Material
N	Wood fibred plaster, Fort Dodge
O	Keene's Cement
P	Finish coat, Fort Dodge
Q	Unfibred plaster, Fort Dodge
R	Cement plaster, Fort Dodge
S	Cement plaster, Fort Dodge
T	Cement plaster, Fort Dodge

The fact that the Fort Dodge district is grinding finer today than it did fifteen years ago is shown by comparing the figures given above with those published in the Geology of Webster county in 1902.[148]

The following tests for fineness of calcined plaster were made by Prof. A. Marston in the summer of 1900, from material purchased in the market. The sieves used were calibrated by standard methods, and the terms, No. 74, No. 100 and No. 200 mesh, stand definitely for the diameters given below. The average diameters of the largest particles passing these sieves are as follows:

148Iowa Geol. Survey, Vol. XII, p. 162.

No. 74 .... 0.229 millimeters = .00901 inches
No. 100 .... 0.115 millimeters = .00452 inches
No. 200 .... 0.069 millimeters = .00271 inches

KIND	PER CENT PASSING MESH		
	No. 74	No. 100	No. 200
Gypsum from Stucco Mills, Ft. Dodge, Iowa	68.3	60.0	44.0
Stucco from Ft. Dodge Plaster Co., Ft. Dodge, Iowa	71.9	66.2	49.3
Baker Stucco, Kansas	72.9	58.3	39.5
Kallolite Stucco, Cardiff Gypsum Plaster Co., Ft. Dodge, Iowa	69.1	63.8	50.2
Baker Plaster, Kansas	68.2	58.7	28.2
Mineral City Wall Plaster, Ft. Dodge, Iowa	72.1	65.4	49.1
Oklahoma Cement Plaster Co., Okarche, Oklahoma Ter.	77.8	70.2	51.3
Flint Wall Plaster, Iowa Plaster Association, Ft. Dodge, Iowa	72.4	64.2	48.1
Acme Wall Plaster, Acme, Texas	74.6	69.2	56.6
Kallolite Wall Plaster, Cardiff Gypsum Plaster Co., Ft. Dodge, Ia.	70.8	65.5	53.5
Stonewall Plaster, Ft. Dodge Plaster Co., Ft. Dodge, Iowa	72.4	66.1	54.0
Duncomb Wall Plaster, Duncomb Stucco Co., Ft. Dodge, Iowa	63.8	57.8	43.6

Another interesting series of fineness tests was made in the laboratories of the State University of Iowa in 1918, most of the samples used being the finer forms of calcined plaster. The material was milled at various points in the United States, and in the series are two samples of wall plaster from mills outside of the state.

SAMPLES. The fourteen samples on which these tests were performed were, with one exception, obtained from the manufacturers. Hereafter, reference to these samples will be made by their laboratory numbers which were as follows: A, B, C, D, E, F, G, H, I, J, K, L, M, and X.

FINENESS. In the determination of fineness Tyler standard screen scales, shaken in a Tyler Ro-Tap Sieve Shaker, were used. The sieves were placed in the machine in the order of size, the coarsest on top. Fifty grams of the material were placed on the top sieve and shaken for twenty minutes. The residues on each sieve and in the pan at the bottom were then weighed and percentages were calculated. The following table shows the percentage retained on the different sieves for each sample:

PERCENTAGES RETAINED

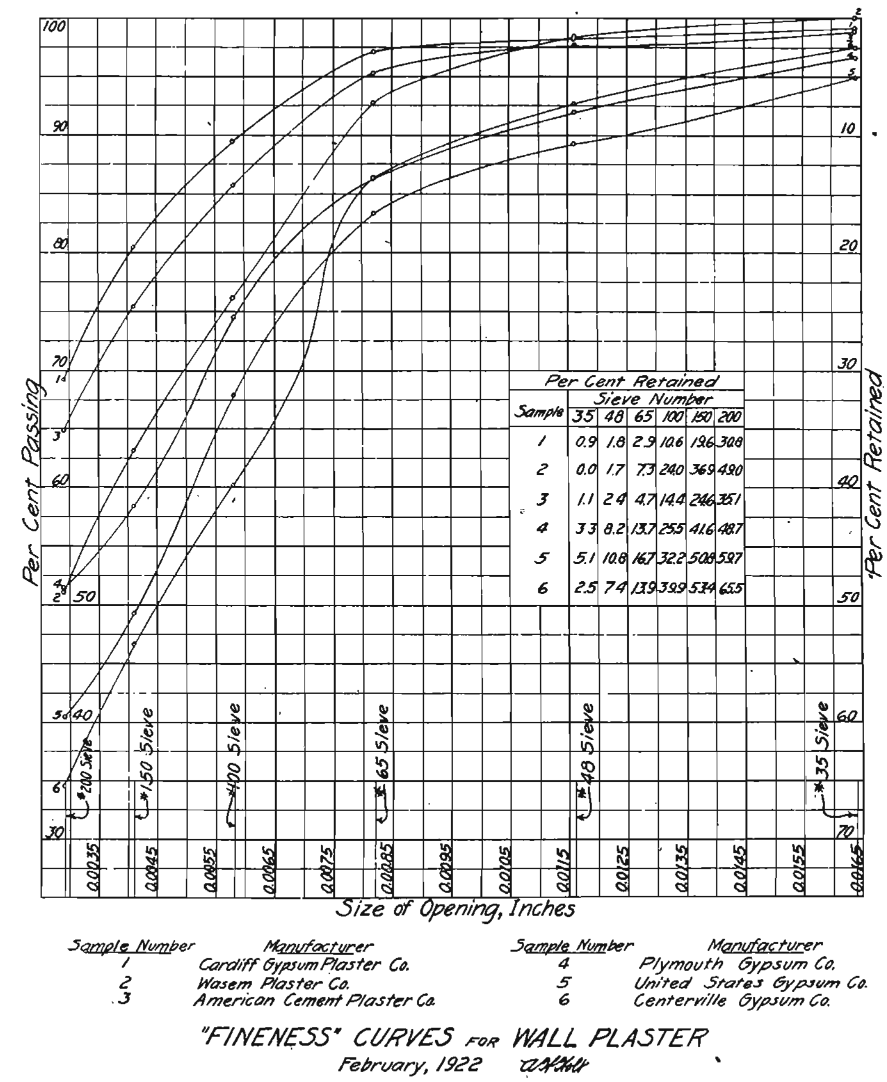
SAMPLE	SIEVE NUMBER No. 48	No. 65	No. 100	No. 150	No. 200
A	2.9	2.9	8.7	16.0	14.1
B	0.2	1.9	6.3	20.7	21.1
C	0.4	0.2	1.9	18.3	25.4
D	2.5	0.8	15.4	40.1	16.3
E	0.7	0.6	5.1	26.2	26.3
F	0.5	0.2	1.1	10.0	26.7
G	4.4	3.0	7.6	7.7	10.1
H	10.0	8.1	14.1	19.1	15.7
I	1.1	2.7	11.3	14.1	12.2
J	0.2	0.2	2.4	44.5	14.2
K	0.2	0.4	4.9	38.4	13.3
L	4.7	6.3	11.5	10.0	7.8
M	4.6	3.4	9.7	21.7	9.5
X	0.1	0.5	2.0	4.4	5.5

The fourteen samples shown above may be described as follows:

LABORATORY NUMBER	DESCRIPTION
A	Plaster of Paris, Fort Dodge, Iowa
B	Structolite, Fort Dodge, Iowa
C	Moulding plaster, Blue Rapids, Kansas
D	Moulding plaster, Blue Rapids, Kansas
E	Moulding plaster, Southard, Oklahoma
F	Moulding plaster, Southard, Oklahoma
G	Wall plaster, Grand Rapids, Michigan
H	Wall plaster, Grand Rapids, Michigan
I	Stucco, Fort Dodge, Iowa
J	Moulding plaster, Fort Dodge, Iowa
K	Dental plaster, Fort Dodge, Iowa
L	Plaster of Paris, Fort Dodge, Iowa
M	Plaster of Paris, Fort Dodge, Iowa
X	Dental plaster, bought of local dealer at Iowa City

Fineness tests of 1922

In the autumn of 1921 another series of samples of wall plasters was collected by Mr. A. H. Holt of the Department of Civil Engineering of the State University of Iowa and was tested for fineness in order to secure the latest information regarding presentday practice in grinding gypsum. The data gained from these sieve analyses are incorporated in the following chart, figure 37. Each curve on the chart represents the results of three to six separate tests on each sample. Tests were continued until results seemed to make it a warranted conclusion that the curve to be plotted would fairly represent the sample.



Sample	Per Cent Retained — Sieve Number 35	48	65	100	150	200
1	0.9	1.8	2.9	10.6	19.6	30.8
2	0.0	1.7	7.3	24.0	36.9	49.0
3	1.1	2.4	4.7	14.4	24.6	35.1
4	3.3	8.2	13.7	25.5	41.6	48.7
5	5.1	10.8	16.7	32.2	50.8	59.7
6	2.5	7.4	13.9	39.9	53.4	65.5

FIG. 37.—Curves illustrating fineness of grinding of Iowa plaster. Prepared by Dept. of Engineering, State University of Iowa.

Plasticity and fineness

In a general way and within certain limits, the plasticity of plaster, one of its most important characteristics, is increased by fine grinding. The speed of set is also somewhat increased, and rather strikingly so if the fine grinding is done after calcining, as is the custom where certain types of rotary calciners are used. The following figure by Winterbottom,[149] figure 38, shows curves that record the setting time and rise in temperature of four sets of samples two samples in each set, one ground to pass a sixty mesh screen and the

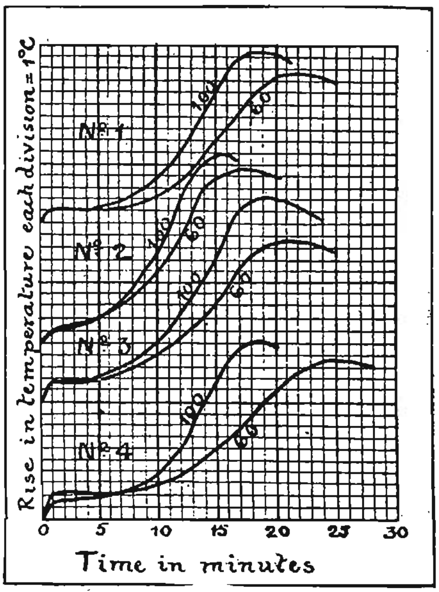


FIG. 38.—Effect of fine grinding on speed of set as shown by rise in temperature. The diagram illustrates four samples each ground after calcining to pass 60 mesh and 100 mesh screen. After Winterbottom.

other to pass a hundred mesh screen. All of the samples were ground after calcining.

Calcining is the process of partly or completely dehydrating gypsum by heat. In chapter XII the nature of the products resulting from calcining gypsum at various temperatures is considered at some length. Two distinct groups of calcined gypsum products are recognized in the arts. The first and more important group consists of gypsum that has been calcined at temperatures not exceeding 400° F. The second group includes gypsum products resulting from calcination at high temperatures, that is from 1652° to 2552° F. (900-1400° C.).[150]

Calcining

Most of the plaster of Paris and wall plaster made in America

[149] Gypsum and Plaster of Paris, Bulletin No. 7 Dept. of Chemistry South Australia, 1917.
[150] See Chapter XII for high temperature calciners.

is calcined in especially constructed vertical cylinders called in the trade "kettles". Continuous rotary calciners are used in three or four American mills and are used to some extent in other countries. Kilns and ovens of unusual design are employed to produce special kinds of plaster of Paris in Germany, France and England.[151]

Kettle calcining

Most American gypsum mills calcine in kettles holding eight, ten, twelve or fifteen tons, those of ten tons capacity being most common. The kettle consists of a steel shell cylindrical

FIG. 39.—Calcining kettle with stirrer, and portions of sectional bottom and lip ring. Courtesy New York Geological Survey.

in shape, eight or ten feet high and with the bottom arching up from six to twelve inches. The shell is made of steel from three-eighths to six-eighths inch thick and the bottom may be either cast iron or steel and varies in thickness from one inch to three inches. In some instances sectional bottoms of six pieces are used. A kettle shell and section of such a bottom are shown in figure 39.

Four flues are commonly present in each kettle, and they may

151 For description and illustrations of many of these kilns see "Der Gips" by V. Waldegg

be placed about eighteen inches from the bottom as shown in figure 39 or one pair may be so placed and the other pair twelve or fourteen inches above them, as shown in figures 40 and 41. The kettle shell is enclosed with fire brick leaving

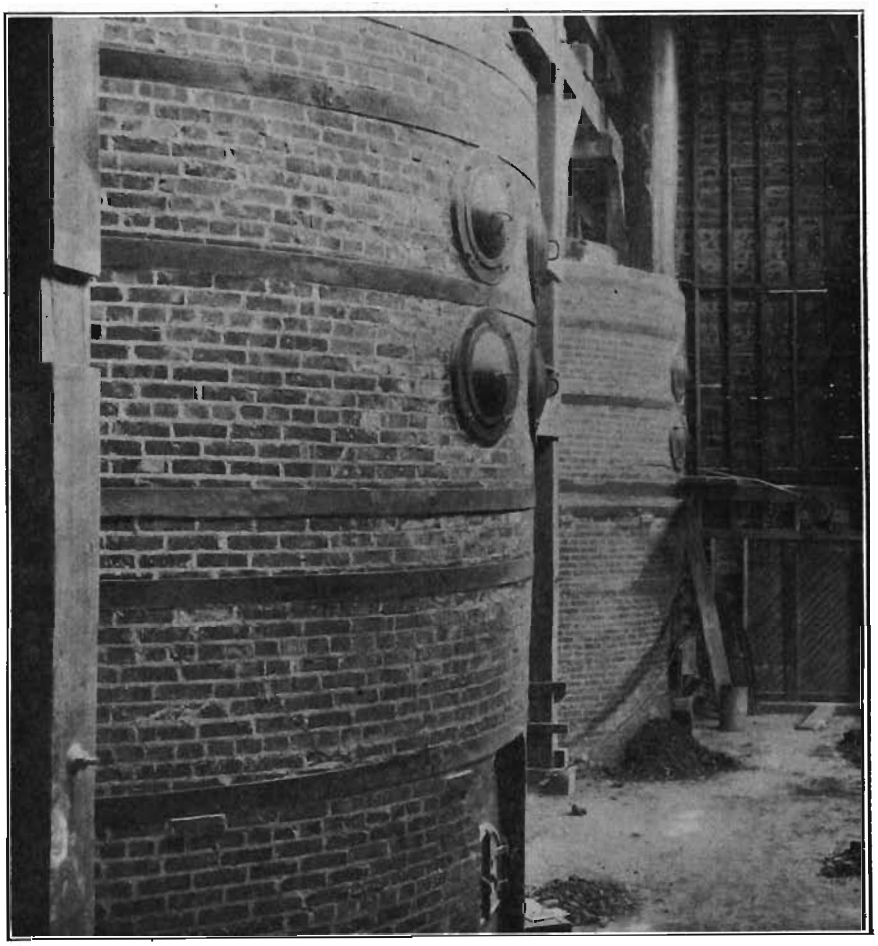


FIG. 40.—Exterior of calcining kettle showing the banded brick jacket and clean-out ports opposite flues. Courtesy Centerville Gypsum Co.

a space of six to fourteen inches between the brick and the shell itself. The kettle rests on a heavy cast "lip ring" a section of which is shown in figure 39. The lip ring is carefully protected by fire brick from direct exposure to the heat of the fire box. There is a space of four to seven feet between the grates and the fire box, and the whole design of the kettle

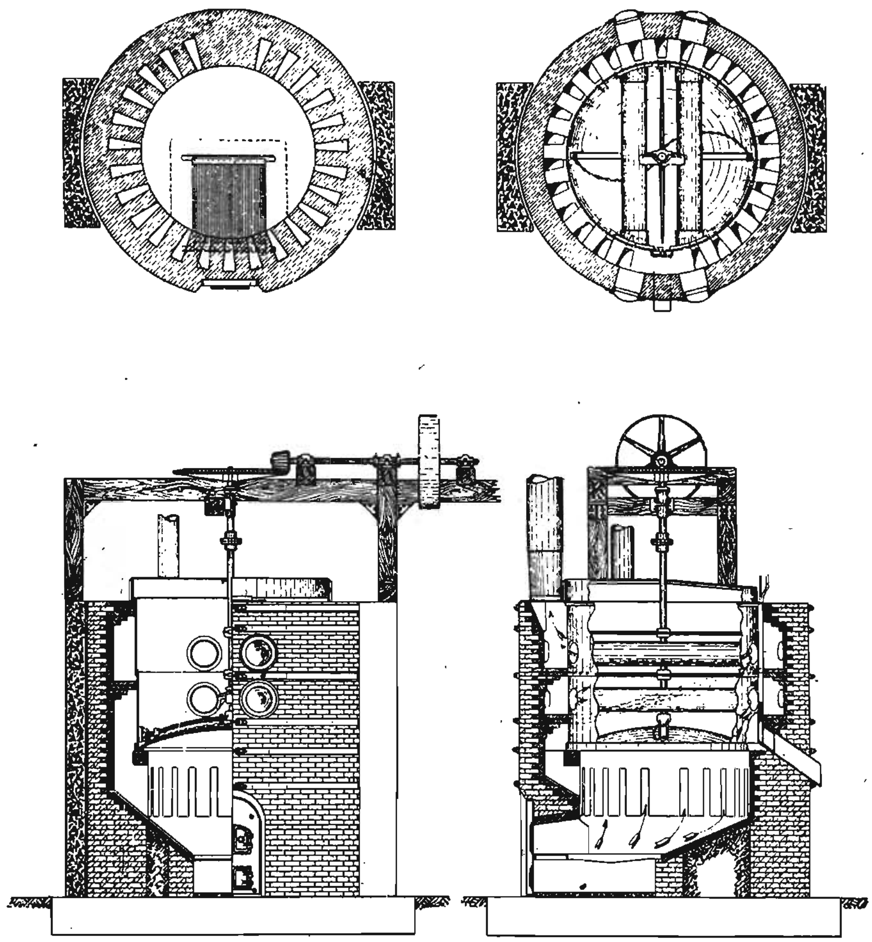


FIG. 41.—Diagram illustrating calcining kettle and setting. In figure in upper right hand corner note the two stirrers and chains dragging the bottom, attached to lower stirrer. Courtesy Ehrsam Mfg. Co.

is intended to distribute the heat on the sides and through the flues of the kettle so that the bottom shall not be exposed to excessive temperatures. The heat and furnace gases pass out through ports below the fire brick that protect the lip ring, into the space at the sides of the kettle. These ports are not directly opposite the flues, and baffles made of fire brick and placed between the steel shell and the outer brick wall, compel the heat and gases to wholly cover the lower sides of the kettle before they can escape through the flues and pass out to the stack. The stacks are high enough to secure a strong draft and there is a good deal of actual combustion between the side walls of the kettle, and in the flues. A high percentage of inflammable gas passes to the stack and is lost and from this point of view kettle calcining is not economical of fuel. Figure 41 shows a typical kettle setting. The vital point in a calcining kettle is the bottom. The greatest trouble in connection with the operation of a calcining kettle comes from leaking through the bottom, or at the contact of the shell and bottom with the lip ring. The difficulties in this connection have steadily increased as the gypsum has been more finely ground. Hot gypsum ground so that ninety per cent passes a hundred mesh screen, flows almost like water and will escape through very minute cracks. A small leak into the fire box will most effectually smother the fire. Steel bottoms do not crack as readily as cast iron, but they may buckle badly and pull away from the sides thus causing trouble as serious as cracking.

Suitable kettle coal

A free burning coal giving a long flame and plenty of gas for combustion about the sides and in the flues of the kettle gives better results than a coking coal which tends to focus the heat on the bottom.

Drafts should not be allowed to strike the hot kettle bottom and when the door is opened for firing it should be closed as quickly as possible. Because of these conditions gas, either natural or producer, and fuel oil make most excellent calcining fuels. They are easily regulated and the heat can be quickly increased or decreased as the kettle is charged or the contents drawn off into the hot pits.

Mechanical agitation

As gypsum is a poor conductor of heat mechanical agitation is necessary during the calcining process to prevent overheating of the material near the bottom, sides and flues and underheating of the more remote material. This agitation is secured by a sweep attached to a shaft that is pivoted in the kettle bottom and is driven by bevel gear above the kettle. To this sweep chains are attached which drag over the bottom and keep the plaster agitated. The life of a kettle bottom depends in part upon the success of the agitating devices in preventing the plaster from lying dormant on the bottom. A second sweep is attached to the shaft just above the flues. The great quantities of steam which are given off aid materially in agitating the mass in the kettles. In calcining gypsite scrapers are used on the sides as well as on the bottom of the kettle.

The amount of fuel required for power purposes in calcining gypsum for ordinary wall plaster (through the first settle) is about one ton of coal for twenty tons of gypsum calcined. One ton of coal is fired under the kettles for every sixteen tons of calcined plaster drawn from them.

Fuel requirements

The chemical changes that take place during the calcining of a kettle of gypsum are considered in chapter XII on the Chemical Nature of Calcined Gypsum. These chemical changes correspond to definite temperatures and are accompanied by certain characteristic manifestations. When the temperature reaches 262° F. (128° C.) steam begins to come off very rapidly, due to the breaking up of the molecules of water of crystallization. It is quite likely that the self recording therometers commonly used to register kettle temperatures will not run quite so high when the "first boil"—as this stage is called—begins, but as shown later in chapter XII, the material nearest to the heated surfaces has, at least in places, reached this temperature. The temperature of the kettle, which had been rising rapidly, now remains almost stationary, while the mass within the kettle "boils" violently. The length of time that the boiling at this stage continues depends on the size of the kettle and the vigor with which it is fired, but in average practice it ends in about forty-five minutes. The temperature begins to rise rapidly again and the plaster in the kettle becomes relatively quiet,—"enters the first settle."

First settle

It is the generally accepted opinion that wall plaster made from material drawn from the kettles during the first settle works more easily—is more plastic—than that made from material that has been further calcined. For wall plaster, therefore, the contents of the kettle are generally discharged when the temperature is between 330° F. and 340° F.

For certain purposes it is thought desirable to carry calcination further. At 325° F. (163° C.) the gypsum begins to boil violently again, perhaps more violently than before. This continues for thirty or more minutes, depending on the size of the kettle and the vigor with which it is fired. Then the material becomes quiet and is drawn off as "second settle" plaster, at 390° F.

Second settle

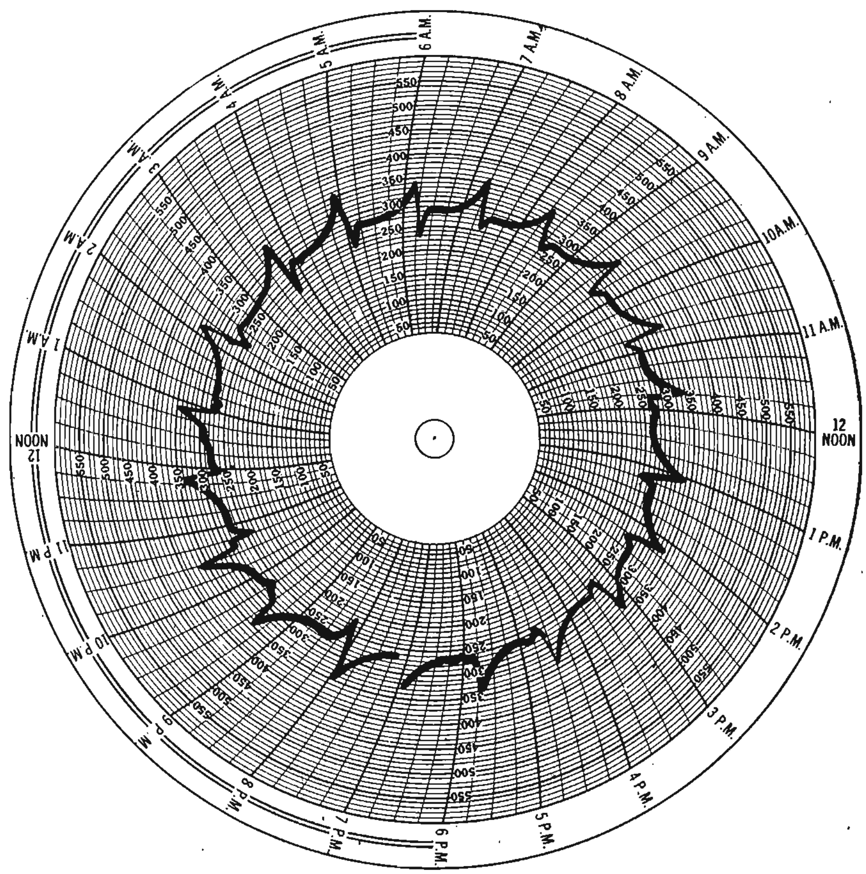


FIG. 42.—Chart from self-recording thermometer showing changes in temperature for twenty-four hours in calcining kettle. Described more fully in the text.

As set out more fully in chapter XII second settle plaster lacks the fatty plastic nature of first settle material. The plasterer characterizes it as short working. It is preferred, however, for moulding, pottery and casting plaster on account of its greater density and strength.

Uses of second settle calcined gypsum

Figure 42 shows a chart from a self recording thermometer for recording temperatures in a calcining kettle. The capacity of the kettle was ten tons, and it took, as the chart shows, twenty charges in twenty-four hours. It received, therefore, 200 tons in one day and delivered 168 tons of calcined plaster, allowing 16 per cent for shrinkage in calcining. The plaster was drawn at 340° F., but the thermometer ran up another ten degrees during the emptying of the kettle. The sharp downwards stroke in each curve represents the charge of cold gypsum with which the kettle was again filled. The line rises sharply each time till 270° F. is reached. The first boil is then fairly under way. It flattens out till this stage is concluded. The kettle was emptied each time just as the second boil started. The time required to calcine gypsite is very much longer than that necessary to calcine ground rock gypsum. If the gypsite has not first passed through a dryer, from six to eight hours may be needed to calcine a single kettle charge, consequently kettles with large capacity are commonly used in gypsite mills.

Calcining Gypsite

It is customary to install over each kettle a dust collector, with baffles so arranged that the dust will be retained without condensing the steam. This dust is finer and faster setting than the regular kettle product and it is either drawn off for uses in which these properties are not objectionable, or it is returned to kettle or hot pit in such a way that it is thoroughly mixed with the larger mass, as otherwise plaster with irregular set would result.

Dust collectors

The kettle is discharged through the wicket into the hot pit. It is highly desirable that this valve be tight and that no raw or partly calcined gypsum is allowed to leak into the hot pit, for raw gypsum acts as an accelerator and a plaster with uneven set would result. The hot pit is usually made of concrete, with one steeply sloping side so that the calcined plaster will run readily to the screw conveyor that extends along the lower side of the pit. The hot pit should be covered to exclude any dirt or raw gypsum, and to prevent the dust and steam, which come off in a cloud when the kettle is discharged, from escaping into the building. A flue from the pits through the roof to the open air is often built to dispose of the steam and prevent condensation in the hot pit. Figure

Hot pit

43 gives a cross section of a calcining mill which shows these details.

Cooling the plaster

Spiral conveyors and elevators between the hot pit and the bins above the packers serve the double purpose of aerating and cooling the plaster and transporting it to the point desired for further treatment.

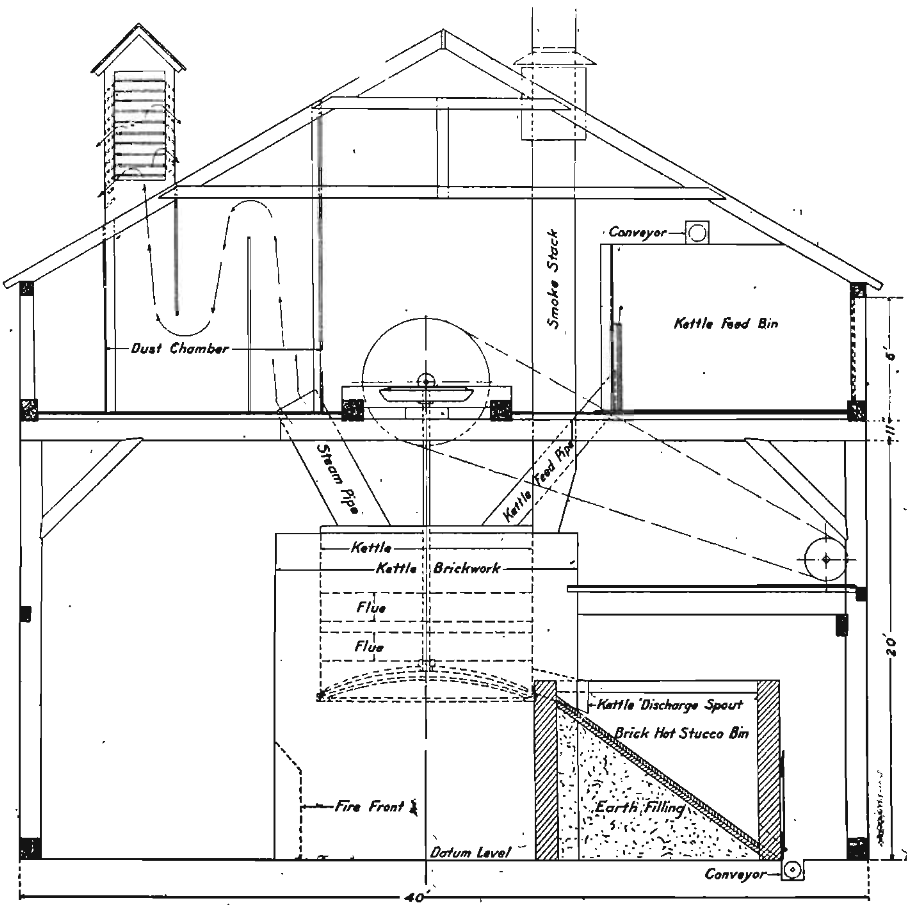


FIG. 43.—Cross section of calcining department of a gypsum plaster mill. Courtesy of Department of Mines, Canada.

Rotary calciners

Calcining in rotary kilns, which is the universal method employed for Portland cement, has made but limited headway in the gypsum industry. Numerous early attempts proved to be failures and the pioneers in the industry invariably came back to the kettle process.

In 1901 the writer[152] described a continuous calciner which he found in operation at Mannheim, Germany, as follows:

"The mill of the Rhenish Gypsum Company, located near Mannheim, is so interesting that it will be well to describe it rather minutely at this point in connection with its unique calcining machinery.

German type

"Mannheim is situated on the middle Rhine, fifteen miles northwest of Heidelberg. The works of the Rhenish gypsum industry are located in the village of Wildhof, about four miles north of the city. The plant is modern and fireproof throughout. The roof of the building is made of gypsum boards covered on the outside with asphalt, the inner walls are made of the same material, while the floors are made out of estrick gypsum. In this mill fine grinding of the gypsum is postponed till after calcining. When the material comes from the crushers and nippers it varies in size from the finest powder to fragments as large as an ordinary hickory nut. Varying thus in size, the material goes directly to the calciner.

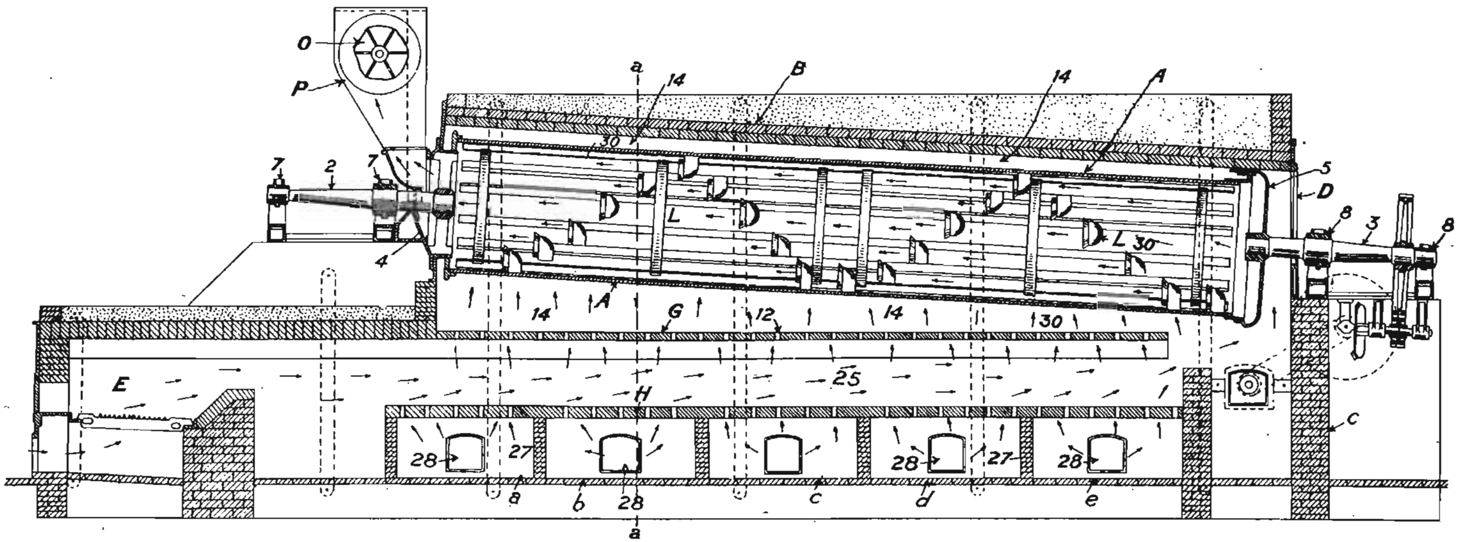
"The calciner consists of a fire box with an automatic stoker, which is placed in front of and connected with a chamber containing a rotating cylinder. Above this cylinder is a chamber called the forewarmer, through which a spiral conveyor passes, from end to end. A pipe leads from the rotating cylinder to the forewarmer, and connects at the other end with the chimney. Connected with the fire box is a fan by which a forced draft is secured. In the figure this fan, instead of being connected with the fire box, is shown connected with the rotary cylinder. The fire box is heated to a high temperature, and the draft, forced by the fan, passes through the rotating cylinder, and then through the forewarmer. The gypsum is conveyed by bucket elevators from the crushers to a bin above the calciner and thence it flows under the influence of gravity into the forewarmer, through which it is carried by the spiral conveyor. It then falls directly into the rotary cylinder below. Shelves or buckets on the inside of this cylinder pick up the material and elevate it as the cylinder rotates. When the material nears the top the slant of the shelves is so great that it falls again to the bottom. This process of raising the gypsum and allowing it to fall is constantly repeated. The strong draft of hot air passing through the cylinder from the fire box strikes the gypsum as it falls from top to bottom and moves the fragments toward the rear with a velocity inversely proportional to their size. The coarser material moves more deliberately, and thus is exposed to the

152 Geology of Webster County, Iowa Geol. Survey, Vol. XII, pp. 213-215.

heat longer than the finer and more readily calcined particles. In this way, though the material entering the rotating cylinder varies greatly in fineness, the finer is not "dead burned" and the coarser is sufficiently calcined. All of the heat has not been exhausted from the air in passing through the rotary cylinder, and this is for the most part saved by forcing the air, after it leaves the cylinder, through the forewarmer. In this process the heat is so completely utilized that the air and furnace gases pass to the chimney with a temperature of only 80° C. Between the forewarmer and the chimney the dust chamber is situated. Here all of the finer particles are allowed to settle and the air passes on to the chimney practically free from dust. No gypsum was seen about the outside of the mills and the roof showed no trace of dust, while within everything was dust free except the grinding and sacking rooms. To calcine one ton of gypsum by this Mannheim method experience has demonstrated that on an average only 100 pounds of rather inferior bituminous coal is required. An automatic recorder indicates constantly the heat of the rotary cylinder, and this, with the mechanical stoker, insures an even temperature during the entire process of calcining. From the rotary cylinder the gypsum is again elevated to the floor above, and passes through a spiral conveyor which is surrounded with a water jacket. Here the gypsum is cooled and passed on to the sieves. That portion of the gypsum which does not need further grinding is separated by the sieves and the rest goes to the vertical mills."

The Cummer process

Three or four American mills use a calciner of the Cummer type. Plate XI illustrates this machine and figure 44 shows end elevation and section. It consists of a cylinder thirty or more feet long and five feet in diameter. It is slightly inclined and its weight is carried by trunnions. It is rotated by a gear drive attached to one end. The cylinder is inclosed with brick at sides and top, and by metal plates at the ends. Hot gases generated in a furnace fed by automatic stokers are mixed with air from ports beneath the rotating cylinder and this air enters the cylinder at the lower end and through specially designed funnels along its sides. The gypsum, which is generally crushed to pass a three-quarters inch ring, is fed into the cylinder from a hopper at the upper end. Longitudinal shelves on the inside of the cylinder carry the gypsum part way up with each rotation. In falling to the bottom the gypsum passes repeatedly through the hot gases and the



Rotary calciner, Cummer type, used in some gypsum mills. Courtesy of Department of Mines, Canada.

finer material is caught by the air current stimulated by a strong fan, and passes with the hot air to a dust room where it is gathered by a screw conveyor rotating at the bottom of the room. A recording thermometer notes accurately the temperature, which is controlled within rather narrow limits.

As originally constructed and as recommended by Mr. Cummer, the inventor of this device, the gypsum from the calcining cylinder passes to large bins where, shut off from the air, the calcining of the larger lumps which were not completely calcined in the cylinder, is completed. Some operators have found the use of such bins unnecessary and pass the gypsum

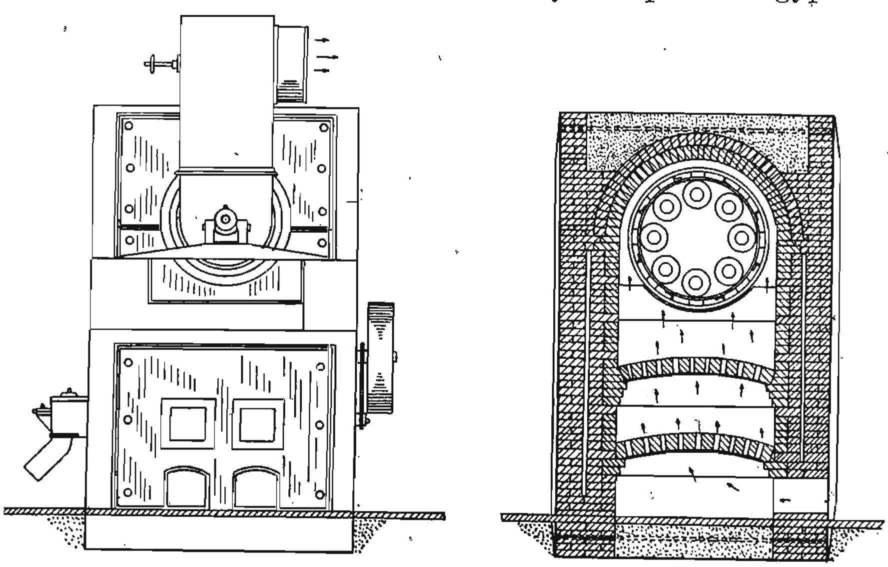


FIG. 44.—End view Rotary calciner. Cummer type. Courtesy Department of Mines, Canada.

from the calciner directly to grinding mills. It is probable that in these mills the calcining is completed, for they receive the gypsum hot from the calciner, and the grinding process itself develops some additional heat.

Cement mill type rotary

In 1917 one gypsum producer broke away from kettle calcining and installed two rotary calciners each seventy feet long, like those used in making Portland cement.

Regrinding

When certain types of continuous calciners are used, all of the fine grinding is done after calcining, and the same types of grinding machinery that were described earlier in this chapter may be used.

Many mills grind to moderate fineness, and then screen the plaster after calcining and regrind the tailings.

Screens

A shaking or tapping screen is preferred to a rotating screen for classifying gypsum at any stage in its manipulation on account of the ease with which the screen clogs or gums up.

The setting time of plaster ground after calcining is shorter than that of plaster made from material ground before calcining. This is due to particles of raw gypsum in the center of the coarser fragments, which the regrinding brings to the surface and which act as accelerator.

Plastic gypsum

Attention has recently been called by Mr. Emley of the Bureau of Standards, to the possibility of making a very plastic gypsum by grinding in a closed mill after calcining. This important matter is set out in appendix VII. This process of regrinding seems to bring about an equalization of the water of crystallization in the calcined mass so that the final product is composed wholly of the hemihydrate. Its plasticity is remarkable so that it can be used as a finish coat without admixture of lime. It should be noted that this process of making plastic gypsum is in use at the Iowana mill at Fort Dodge.

Purpose of mixing

Various ingredients are mixed with the calcined plaster in order to produce a substance best adapted for covering interior walls. The materials are added for two purposes; first, to aid the plasterer in applying the material to the wall; and second, to reduce the cost per yard of finished surface. Materials added to modify the physical properties of the plaster so as to simplify its application are,

Materials mixed

retarder; fibre, either hair or wood or sisal; hydrated lime and clay. Sand is added, either at the mill or on the job, to reduce costs.

Retarder

In order to give the workmen ample time to mix the plaster with sand and apply it to the wall a retarding substance is added at the mill. The nature of the retarders used is discussed in chapter XIX. The amount of retarder required depends on the nature of the material used for the purpose and on the nature of the plaster. Gypsite plaster requires little or no retarder. Calcined gypsum made from rock gypsum sets in fifteen or twenty minutes and it is customary to add retarder in sufficient quantity to slow the set to two hours, even after it has been mixed with sand, which has an accelerating tendency.

Fibre is added to give more adhesion to the plaster while it is being applied and to prevent its dropping off behind the lath. Any benefit derived from it is confined to the period of application, as the strength that it imparts to the plaster is very small and is not needed to supplement the strength of the calcined plaster. From four to six pounds of long fibred goat hair are commonly mixed through each ton of neat gypsum plaster. The goat hair is often supplemented by one or two pounds of sisal or similar vegetable fibre. Some producers use only cattle hair. Wood fibred plasters are commonly recommended for use without sand and are generally sold where sand is scarce and expensive. Thirty or forty pounds of shredded wood are used in each ton of plaster. Soft, non-staining woods are chosen for this purpose, bass, willow, poplar, buckeye and similar trees furnishing most of the fibre.

Fibre

The hair comes in compact bales and must be shredded before it can be mixed with the plaster. Two or three machines are on the market for this purpose. A central disc with projecting teeth is revolved rapidly near a stationary disc of similar construction and the matted hair is thrown into an opening near the center of the revolving disc and frayed between the stationary and revolving teeth till it is discharged by centrifugal force, in a loose condition, at an opening on the outer edge of the containing case.

Hair picker

A machine for shredding wood for mixing with plaster is much more elaborate and for its operation requires twenty to thirty horse power. The log cut to proper length and barked, is pressed against a set of saw toothed discs on a rapidly revolving shaft to which they are firmly keyed. The log rotates slowly and is held against the revolving discs with even pressure. In the same proportion that the diameter of the log decreases its speed of rotation is increased by a cone drive so that the length of the fibre remains fairly constant. The fibre is in many cases taken from the machine by a fan and delivered to a fire proof bin.

Wood fibre machines

In order to shred properly the wood must not be too dry. In another type of fibre serial blocks are clamped to a rotating disc and remain stationary while the disc slowly revolves and brings the blocks of wood in succession in contact with rapidly revolving knives which shred the wood with the grain.

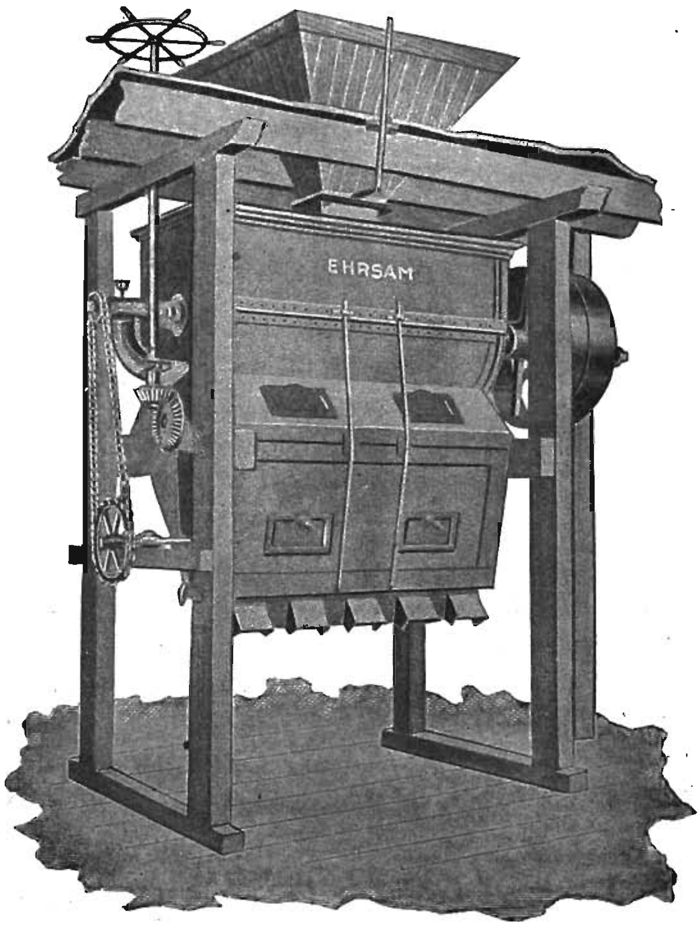


FIG. 45.—Plaster mixer. Courtesy Ehrsam Mfg. Co.

The purpose of this machine is to produce the maximum amount of long fibre.

The ingredients in proper proportion are placed in a hopper over the mixer, which is usually built to take a charge of a **Mixing** ton. Some care must be taken when mixing wood fibre plaster, not to let the retarder come in contact with the damp wood for this results in the retarder sticking to the fibre, and small white spots of over retarded plaster appear when the plaster is applied on the wall.

In the mixer a series of blades attached to a revolving shaft secure a thorough mechanical mixing. The mixer may discharge into a sacker for hand tying or may be attached directly to a valve-packer. An illustration of one type of mixer in use at gypsum mills is shown in figure 45.

Packing machinery is used almost universally in Portland cement mills and the same type of packer is used in some gypsum mills. On account of the fibre in gypsum plaster

Automatic packing

some modifications were found necessary in adapting the cement packer to wall plaster. The mouth of the plaster bag is securely closed while the bag is empty and the plaster is injected through a valve in one corner of the bottom and its loss is prevented by a flap which closes the opening under pressure of the contents of the bag. Figure 46 shows a packer of the type used in gypsum mills.

The plaster is generally conveyed to the car in truck loads

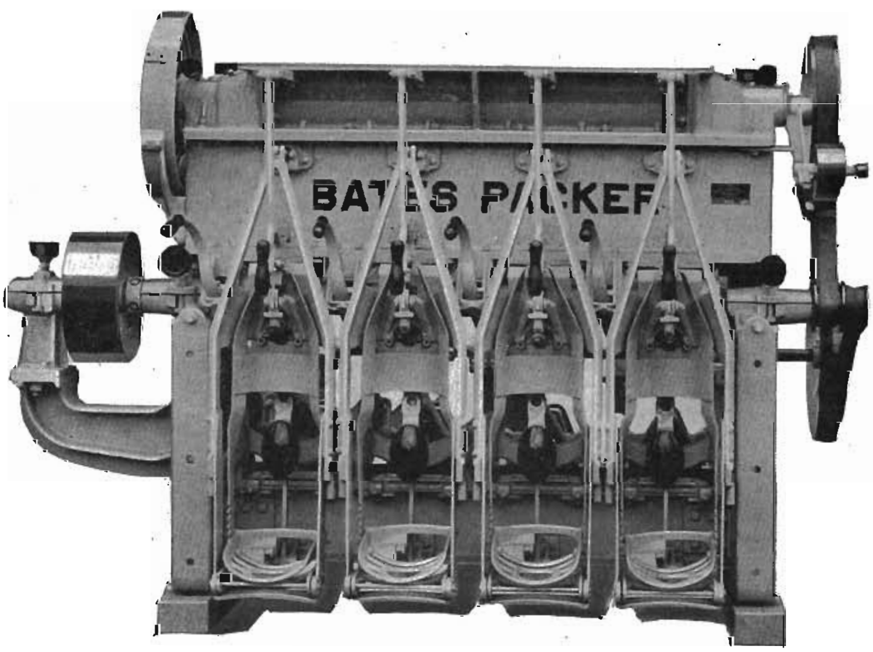


FIG. 46.—Automatic bag filler, packer and weigher. Courtesy Bates Valve Bag Co.

of five bags each. When paper bags are used care is taken to see that nails and projections that would tear the bottom bags are removed. Usually a layer of felt paper is placed on the car floor as additional protection and extra paper bags are placed in the car to replace bags that are broken in transit.

Loading and trucking

Calcined gypsum and plaster may be packed either in jute or paper bags. At present jute bags are more commonly used though there is a strong tendency toward the more extensive use of paper. Twelve ounce jute is commonly used though the light grades down to ten ounce are sometimes employed. The package usually holds 100 pounds, and the size of the bag to hold this amount varies with the fineness of grinding. When calcined gypsum is ground so that 90 per cent passes a 100 mesh screen, the size of the bag to hold 100 pounds should be 20 by 36[153] inches.

Bags

The plaster manufacturer usually includes the price of the jute bag with that of the plaster when it is sold, and redeems jute bags of his own brand when returned in good condition freight prepaid, within six months. The bag department where returned bags are cleaned and reconditioned is an important part of a plaster mill.

Where paper bags are used an extra strength is desirable. The size of the package is reduced to eighty pounds. Paper bags cost from a dollar to a dollar and a half per ton of plaster, are sold with the plaster and of course cannot be redeemed.

Paper bags

A chart showing fuel consumption and other items in the manufacture of calcined gypsum is introduced as Plate XII.

153These figures represent the size of the average bag used by the industry. Where special regrinding processes are used a somewhat larger bag is sometimes required.

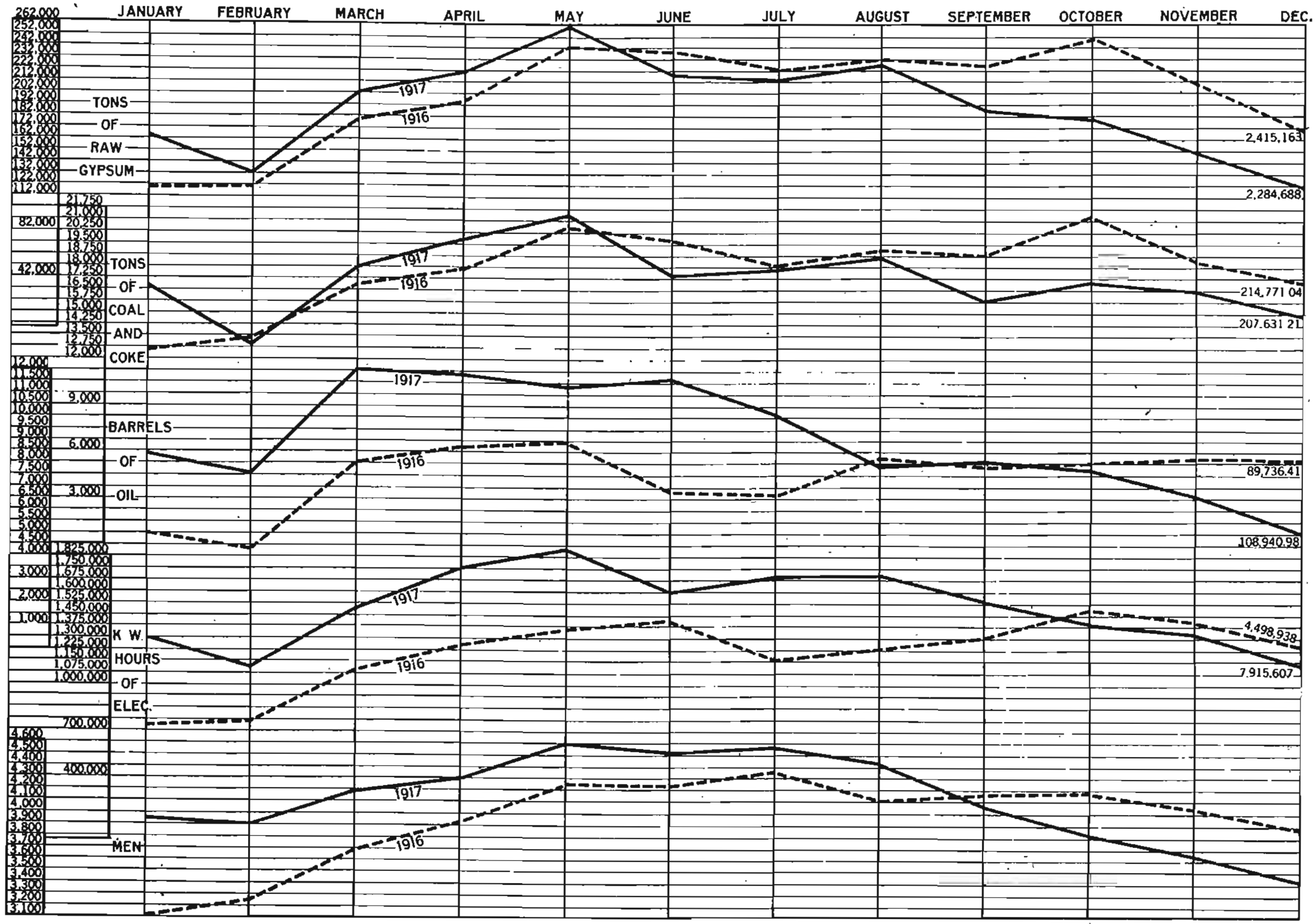


Diagram showing fuel and power consumption of the Gypsum indus try in 1916 and 1917, with fluctuation in monthly output. Prepared by O. M. Knode of the U. S. Gypsum Co.